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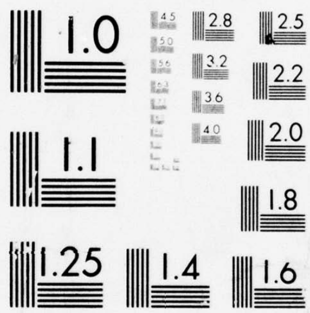

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January 1977

DF LASER PROPAGATION ANALYSIS
Final Report

by

D. R. Woods
W. Flowers
R. E. Meredith
T. W. Tuer
J. P. Walker

for

Naval Research Laboratory
Washington, D. C.

Contract N00173-76-C-0102

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Investigations in support of the NRL effort to obtain a field verified model of the atmospheric absorption of DF laser radiation are reported. New absorption line parameters have been extracted from spectroscopic data in the DF laser region.

A simple analytic model has been developed for each DF laser line. The model allows the laser transmission to be simply calculated for any arbitrary

temperature or humidity. The coefficients for this model are periodically updated by SAI, and the last set of coefficients is included in the report. Included also are plots of the functional dependence of DF laser transmission on temperature and humidity, and tables of the data used to obtain the coefficients.

The atmospheric molecular transmission has been calculated and plotted for all wavelengths in the DF laser region (3.57 - 4.03 μm) and in the CO laser region (4.55 - 5.26 μm).

Micrometers

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DF Laser Propagation Analysis
Final Report

1.0 INTRODUCTION

The objective of this work is to obtain a model of the atmospheric absorption in the DF laser region (3.6 - 4.0 μm) which is verifiable by NRL field measurements. There have been four elements to the basic approach. First, measurements have been made of a large number of fundamental molecular parameters which affect the absorption of DF laser radiation. Second, the absorption of each laser line was calculated using these numerous parameters, and then fit with a simple analytic model containing only a few coefficients. These coefficients give the temperature and humidity dependence of the absorption. Third, NRL compared their measurements with this simple model to establish its validity. Fourth, SAI's computer codes have been rewritten to facilitate checks on the accuracy of the existing absorption coefficients at all the wavelengths between the DF laser lines. The new code, SYNSPC, has been used by NRL and SAI to calculate and plot the atmospheric absorption for comparison with both the NRL interferometer measurements in the field and the SAI laboratory measurements.

The improvements in the modeling of DF laser absorption can be seen in Figures 1 and 2. NRL measurements are compared to both the absorption calculated with the parameters from this study and the absorption calculated with the parameters available prior to this study. It is clear that the measurement of line parameters for which previous estimates were in error has completely eliminated the early discrepancies between the field measurements and calculations.

Figure 1

ABSORPTION VS WATER VAPOR PRESSURE

P1-7

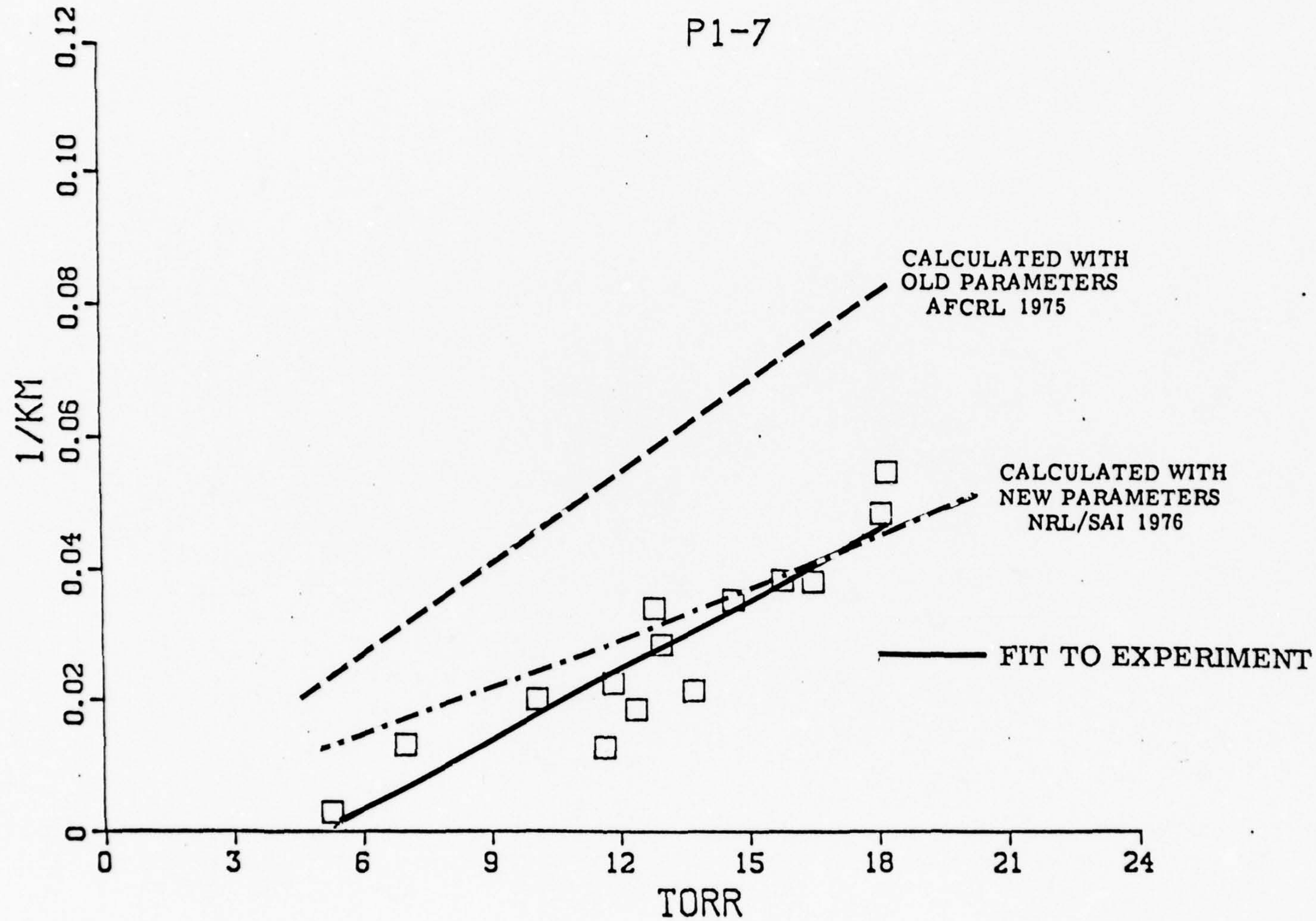
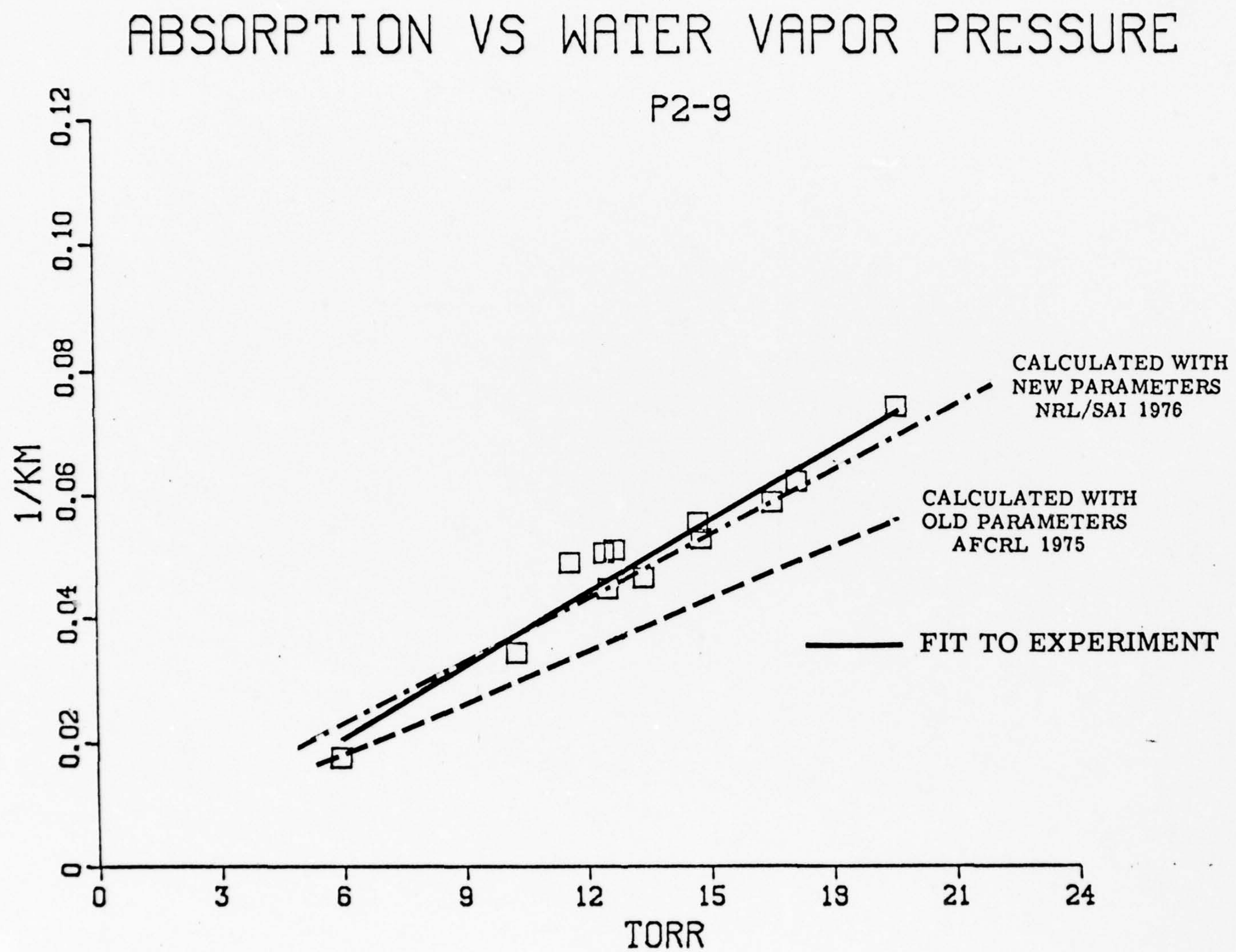


Figure 2


ABSORPTION VS WATER VAPOR PRESSURE
P2-9
0.12
0.10
0.08
0.06
0.04
0.02
0
1/KM
0
3
6
9
12
15
19
21
24
TORR
CALCULATED WITH
NEW PARAMETERS
NRL/SAI 1976
CALCULATED WITH
OLD PARAMETERS
AFCRL 1975
FIT TO EXPERIMENT

2.0 SIMPLIFIED DF LASER ABSORPTION MODEL

A simplified model has been developed for calculating molecular absorption of DF laser radiation. A simple analytic function of atmospheric temperature and water vapor concentration was fit to calculated absorption coefficients for 27 DF laser lines. This provides a convenient procedure for predicting atmospheric absorption of DF laser radiation.

A least-squares fitting code was used to determine the coefficients $a_0, a_1, \ldots, a_5$ in the polynomial:

$$k = a_0 + a_1 T + a_2 p + a_3 Tp + a_4 p^2 + a_5 Tp^2$$

where k is the molecular absorption coefficient (km^{-1}), T and p are the atmospheric air temperature (^oF) and water vapor partial pressure (torr), respectively. The modeling coefficients $a_0 \ldots a_5$ are given in Table 1 for each DF laser line. The calculated molecular absorption coefficients used to derive the modeling coefficients are given in Appendix A. Appendix B gives the calculated points and the analytical curve fits for each DF laser line.

SAI's standard line-by-line computer code [1, 2] was used to calculate the basis molecular absorption coefficients given in Appendix A. These calculations use empirical models of the water and nitrogen continuum based on Burch's measurements [3, 4]. An SAI modified version of the 1975 AFGL line parameter compilation was used along with preliminary values of the DF laser wavenumbers [5]. The subsequent published wavenumbers [6] are slightly more accurate. The AFGL compilation was modified to include recent SAI line parameter measurements [7] for absorption lines near the $P_1(7)$, $P_1(8)$, $P_1(9)$, $P_2(7)$ and $P_2(9)$ DF laser lines (see Table 2). The calculations include the effects of self broadening for H_2O and HDO (broadened by H_2O). A nominal

Table 1.

COEFFICIENTS OF LEAST SQUARES FIT
(K=A0+A1*T+A2*PH2O+A3*T*PH2O+A4*PH2O*PH2O+A5*T*PH2O*PH2O)

OF LINE	A0	A1	A2	A3	A4	A5
P3 (12)	7.707E-02	-5.399E-05	2.886E-03	-1.475E-05	2.598E-05	-1.142E-07
P3 (11)	5.389E-02	-6.445E-05	2.642E-03	-1.003E-05	2.219E-05	-7.636E-08
P3 (10)	2.834E-02	-2.718E-05	2.251E-03	-1.044E-05	1.989E-05	-7.822E-08
P2 (13)	2.595E-02	-2.350E-05	2.196E-03	-1.076E-05	1.948E-05	-7.958E-08
P3 (9)	1.595E-02	-9.720E-06	1.967E-03	-9.469E-06	1.727E-05	-6.788E-08
P2 (12)	1.444E-02	-8.468E-06	1.928E-03	-9.274E-06	1.675E-05	-6.511E-08
P3 (8)	3.311E-02	-3.105E-05	1.793E-03	-7.846E-06	1.563E-05	-5.616E-08
P2 (11)	1.949E-02	-2.579E-05	1.724E-03	-7.875E-06	1.527E-05	-5.855E-08
P3 (7)	4.759E-02	-6.768E-05	1.746E-03	-5.042E-06	1.483E-05	-3.983E-08
P2 (10)	4.904E-02	-2.046E-05	1.706E-03	-6.475E-06	1.446E-05	-4.778E-08
P3 (6)	5.252E-03	9.041E-06	1.852E-03	-4.095E-06	1.488E-05	-3.660E-08
P2 (9)	4.915E-03	-7.479E-06	3.512E-03	-5.063E-06	1.384E-05	-4.999E-08
P3 (5)	2.415E-03	-2.647E-07	1.781E-03	-7.167E-06	1.516E-05	-5.045E-08
P2 (8)	3.036E-03	-4.749E-07	2.211E-03	-5.944E-07	1.428E-05	-7.332E-08
P2 (7)	4.517E-04	3.383E-06	6.467E-03	-3.748E-06	3.136E-05	-8.721E-09
P1 (10)	1.625E-03	4.943E-06	2.902E-03	-8.741E-06	2.145E-05	-5.417E-08
P2 (6)	2.426E-04	8.374E-07	4.481E-03	-9.350E-06	2.857E-05	-4.533E-08
P1 (9)	6.694E-03	2.471E-05	3.106E-03	-1.046E-05	2.449E-05	-6.858E-08
P2 (5)	-6.190E-07	2.522E-08	2.564E-03	-9.855E-06	2.140E-05	-7.297E-08
P1 (8)	-2.753E-05	3.094E-07	8.200E-03	1.668E-05	3.569E-05	1.020E-07
P2 (4)	1.511E-04	7.370E-08	4.075E-03	-5.694E-06	2.815E-05	-8.162E-08
P1 (7)	2.462E-03	-8.120E-06	3.099E-03	-1.382E-05	2.618E-05	-1.411E-07
P2 (3)	1.080E-03	-4.180E-07	3.622E-03	-1.442E-05	2.811E-05	-9.978E-08
P1 (6)	5.128E-03	-7.766E-07	6.394E-03	-1.582E-05	4.191E-05	-9.394E-08
P1 (5)	1.472E-03	-3.903E-07	5.495E-03	-1.588E-05	3.929E-05	-1.048E-07
P1 (4)	4.246E-03	-5.801E-06	6.569E-03	-2.773E-06	3.767E-05	-1.464E-07
P1 (3)	1.402E-04	1.009E-05	5.353E-03	-1.449E-05	3.312E-05	-1.586E-07

Table 2.
Modifications to AFCRL Line Parameters Based on SAI Measurements

DF Laser Line Affected	Specie	Position (cm^{-1}) Meas.	Position (cm^{-1}) AFCRL	Strength x 10^{21} $\frac{cm}{molec}$ Meas.	Strength x 10^{21} $\frac{cm}{molec}$ AFCRL**	Half Width (cm^{-1}) Meas.	Half Width (cm^{-1}) AFCRL
2742.997 cm^{-1} $P_1(7)$	HDO	*	2742.882	0.0472	1.4370	0.0990	0.1021
	HDO	*	2743.576	0.3538	1.0000	0.1020	0.0826
	HDO	*	2743.941	2.3030	3.1530	0.1325	0.0984
	HDO	*	2744.147	0.3199	1.0070	0.0862	0.0802
	HDO	*	2744.288	0.4477	0.1337	0.1149	0.0956
2717.543 cm^{-1} $P_1(8)$	HDO	2717.460	2717.456	0.8547	0.2780	0.0983	0.0952
	HDO	2717.750	2717.751	6.0850	5.9670	0.0560	0.0485 ***
	HDO	2717.750	2717.751	6.0850	5.9670	0.0560	0.0485 ***
2691.605 cm^{-1} $P_1(9)$	HDO	2689.779	2689.785	16.740	14.000	0.1090	0.1039
	HDO	2692.746	2692.750	23.340	20.500	0.1084	0.1059
	HDO	2693.495	2693.495	1.1000	1.8670	0.0943	0.0872
	HDO	2695.204	2695.208	16.600	14.600	0.1060	0.0989
	CH_4	*	2691.590	0.2830	0.1080	*	0.0550
	CH_4	*	2691.660	0.2140	0.0818	*	0.0550
2655.861 cm^{-1} $P_2(7)$	HDO	2655.462	2655.459	24.440	19.500	0.0995	0.0956
	HDO	2655.748	2655.746	~0.270	0.5270	*	0.0879
	HDO	2657.332	2657.330	16.690	13.000	0.0981	0.0913
2605.806 cm^{-1} $P_2(9)$	HDO	*	2605.183	5.5830	4.2330	0.0855	0.0855
	HDO	*	2606.311	11.900	8.3670	0.0926	0.0784

* AFCRL value used.

** These strengths are per molecule of HDO while the strengths on the data tape are reduced by a nominal value of the HDO natural abundance to simplify calculations.

*** Two different lines with nearly identical parameters.

factor of 5 times the foreign broadening was used except for $P_1(7)$, $P_2(9)$ and $P_2(7)$ where a factor of 1 was used inadvertently. The factor of 1 may lead to 10% errors for high humidities and will be corrected in the next set of coefficients. The factor of 5 however, may itself lead to errors of 5% since it is just an arbitrary estimate. This is because adequate values for the broadening of HDO and H_2O are unavailable. The temperature dependence of the continua absorption [8], and of the vibrational partition function [9], were included.

3.0 ABSORPTION LINE PARAMETER MEASUREMENTS

The molecular absorption line strength, width, and center wavenumbers are the fundamental parameters required to model molecular line absorption of laser radiation. They are used to obtain the absorption as a function of temperature, pressure (altitude), and concentration. They are also used to determine the coefficients for the simplified expressions (see Section 2) used to expedite the calculation of atmospheric molecular absorption for arbitrary temperatures and concentrations. The absorption line widths, strengths, and relative wavenumbers have been extracted from HDO data for the lines which affect the absorption at important DF laser lines. The HDO data was obtained on a separate NRL contract.

3.1 Procedure for Obtaining Line Strength and Width Values

The basic spectroscopic data was provided on digital cassettes. A TI 733 ASR data terminal has been modified so that it is possible to replace the more expensive digital grade cassettes with two hour audio cassettes. The audio cassettes accept twice as much data allowing longer scans.

The first step in preprocessing is to read the cassette data into a disk file on the computer. The data is edited to remove semicolons inserted by transients during the spectrometer scan, to correct and complete the header information, and to correct data lost or scrambled during transmission to the computer. The data is then stored on a file save tape for future analysis.

The analysis begins with the measurement of about ten absorption line positions on each scan. The wavenumber calibration constants for each scan are determined by a least squares fit of the measured positions to the positions listed in the AFGL data tape [10]. The 100% transmission voltage is calibrated by specifying the transmission at a

few selected calibration points in each set of data (scan). All of this calibration data is added to the data file headings which already contain the calibration values for the sample cell fill and other scan conditions. The computer code SCALDATA is used to preprocess the data. The measured voltages are converted into calibrated transmission values at calibrated wavenumbers using the data from the file heading. Zero transmission calibration data are recorded at the beginning and end of each scan.

Next, the SYNSPC computer code (see Section 4.0) is used to generate calibrated plots of the measured spectrum and to calculate and plot the expected spectrum. These plots are used to select spectral regions containing twelve or fewer lines for extraction of the strength and width parameters. The program FITIN is used to obtain starting absorption line parameters from the AFGL data tape for the particular temperature, pressure, concentration and path length conditions of the scan. The starting parameter values for lines which are not on the data tape (usually D_2O lines) can easily be estimated by inspection of the measured and calculated spectral plots. Using these starting parameters, the program FITLINES (see Section 3.2) is run to extract absorption line strengths and widths from the data.

3.2 FITLINES -- A Program for Automatic Extraction of Absorption Line Parameters from Measured Data

There are quite a number of different techniques which various authors have used to manually extract absorption line strengths and widths from spectroscopic measurements. These techniques are quite well suited to the manual extraction of line strengths and widths from measurements of isolated lines if accurate measurements are made of the 0% and 100% transmission base lines, and if the proper corrections are made for the spectrometer spectral response function and for the choice of the 100% transmission base line. However, these techniques are not at all suitable for the automatic extraction of line strengths

and widths from lines which lie near to, or are overlapped by, a number of other irregularly spaced lines. At this laboratory [7, 11], the manual parametric fit of a synthetic spectrum to the measured spectrum was used previously to deal with this difficult parameter extraction problem. Unfortunately, for overlapped lines, the manual parametric fit requires a highly skilled person, and is very tedious and time consuming.

A new method is now being used to extract absorption line parameters from spectroscopic measurements. It works with isolated and overlapped lines. This method is semi-automatic and the computer codes can be operated by relatively unskilled personnel for the simple cases of overlapped lines. The cases of highly overlapped and multiple lines, however, require the judgment of personnel highly skilled and experienced in extracting absorption line strengths and widths from parametric fits of overlapped lines. The computer code which executes this method is called FITLINES.

With FITLINES, the estimated strengths, widths, and wavenumbers of individual molecular lines expected in the region are systematically varied to get the best least-squares fit to the measured data scan. The starting line parameter estimates are obtained from the latest AFGL data tape, and from the visual inspection of the spectra.

The current version of FITLINES allows the simultaneous fitting of up to 12 overlapped spectral lines. Any arbitrary spectrometer spectral response function can be specified. Convolution of the spectral response function is speeded by 5, 9 or 16 point Gaussian quadrature, depending on the complexity of the spectral response function. The program also corrects any errors in the 100% transmission base line. The code has been written to use efficiently a large number of fine interval (0.001 cm^{-1}) spectral data points, such as may typically be obtained with current data acquisition systems.

A detailed description of the sequence of steps performed by FIT-LINES follows:

(1) The measured spectral transmission values, a measured spectrometer spectral response function, and starting estimates of the line strengths, widths and positions are read in by the code and stored.

(2) The code selects a number of critical wavenumbers for each absorption line and for the regions in between the absorption lines. These points will be used for the first order, nonlinear, least-squares fit of the measured transmission.

(3) The transmission value at the selected wavenumbers is determined from a second-order polynomial fit to the measured data in the $\pm\ 0.3\ \gamma$ region around the selected point. The user may specify other order polynomial fits. For the points chosen between the lines the polynomial fit is made over $\pm\ 0.3\ \gamma_{average}$ region.

(4) The transmission values are calculated at the selected wavenumbers from the estimated starting line parameters or, on successive iterations, from the corrected parameters.

(5) The residual error between the measured and calculated transmission values is computed. If the residual is less than a given level the computation has given a successful result.

(6) If the agreement is not sufficiently accurate, the partial derivatives of the transmission at each wavenumber with respect to the various parameters are computed.

(7) A linear algebraic system, derived from the partial derivatives and residuals, is solved for the corrections to the current parameter values.

(8) The corrections are applied to the estimated parameter values and the sequence of steps (2) through (7) is repeated until an accurate fit is obtained or the specified number of iterations has been performed.

The performance of FITLINES is illustrated in Figures 3, 4 and 5. The solid curve in Figure 3 is the measured HDO and D_2O transmission near the $P_1(7)$ DF laser line. The X's are the calculated transmission values based on the starting estimates of the line parameters. Figure 4 shows the result of three iterations. Here the X's are the transmission values calculated from the parameters determined by FITLINES. The fit converges quickly and gives an excellent representation of the measured spectrum. Figure 5 indicates how it is possible to obtain strength and width parameters of limited accuracy even when the line is weak and the spectrum noisy. The boxes on the top of the figure give the residuals calculated by FITLINES. The residuals are the differences between the transmission determined by a second order polynomial fit to the data around a selected point, and the transmission calculated at the point using the line parameters extracted by FITLINES. The scale is $\pm$ 2%. Thus it can be seen that the typical residual is only a few tenths of a percent.

A similar code has been developed by Chang [12]. It also uses a nonlinear, least-square fit technique to obtain the line parameters for two overlapped lines. A Gaussian instrument spectral response function is used. This allows a more analytical approach to the program. The input data for Chang's code is obtained by digitizing selected critical points from spectral charts.

3.3 Procedure for Obtaining Relative DF Laser -- HDO Line Wavenumbers

The HDO absorption lines and DF laser emission lines were simultaneously recorded on a two-pen chart recorder. Typically each absorption-line, laser-line combination was scanned four times. The relative positions were scaled graphically, and the results of the four measurements were averaged. The current accuracy of the relative position values is 0.015 cm^{-1}. However the contract for the measurements

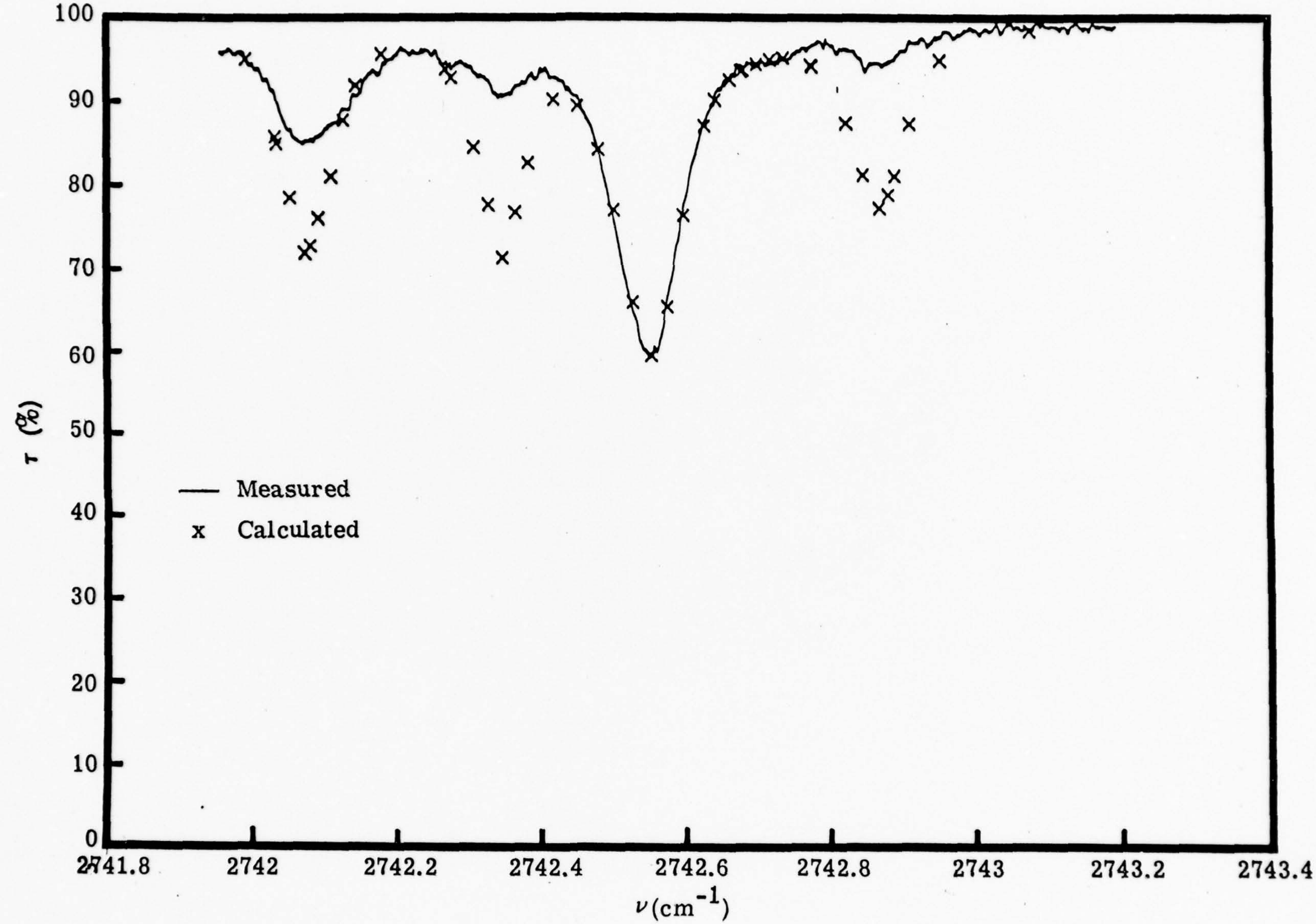


Figure 3. Measured and Calculated HDO Transmission Before Line Parameter Analysis

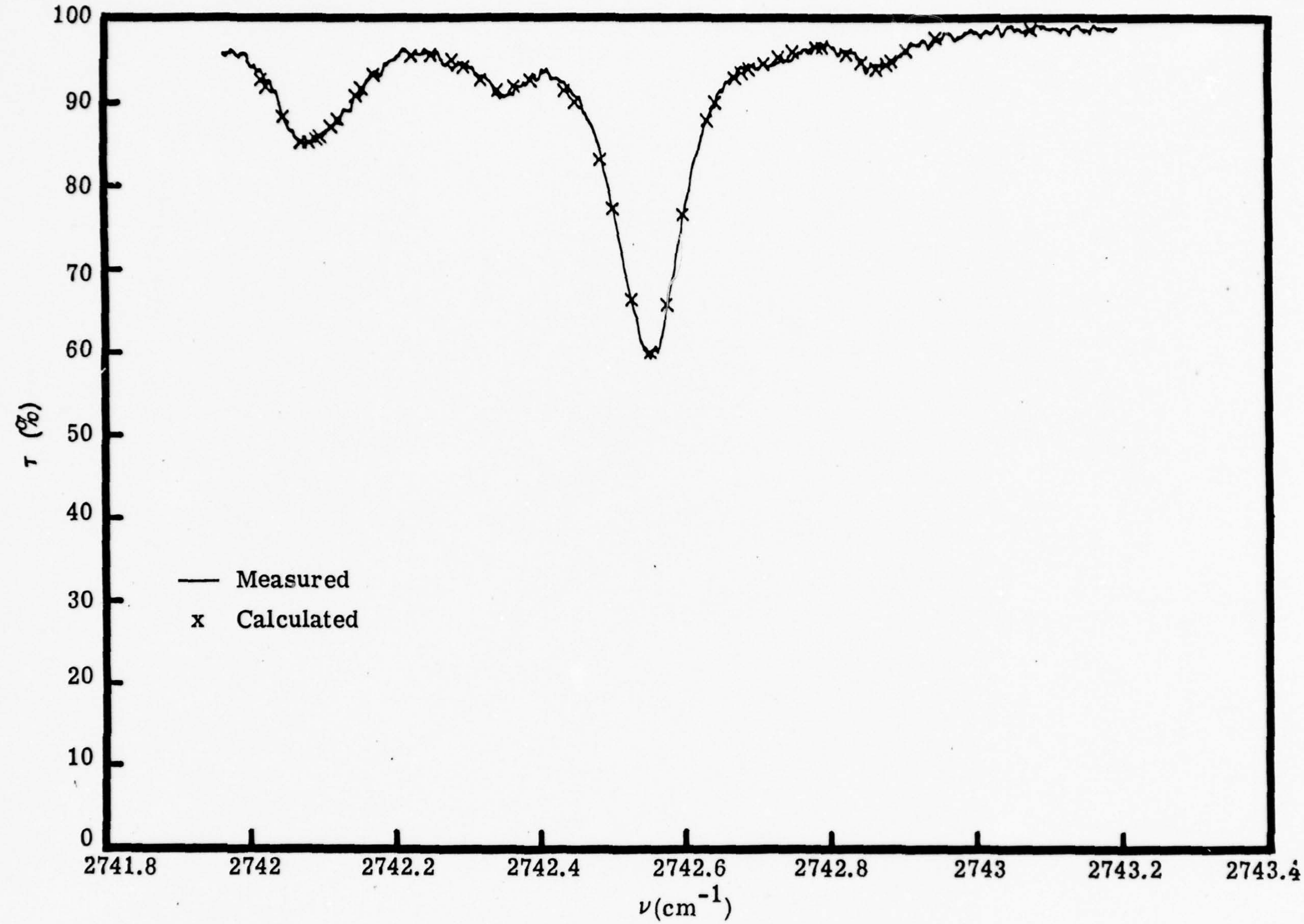


Figure 4. Measured and Calculated HDO Transmission Using Line Parameters Extracted with LINPRA

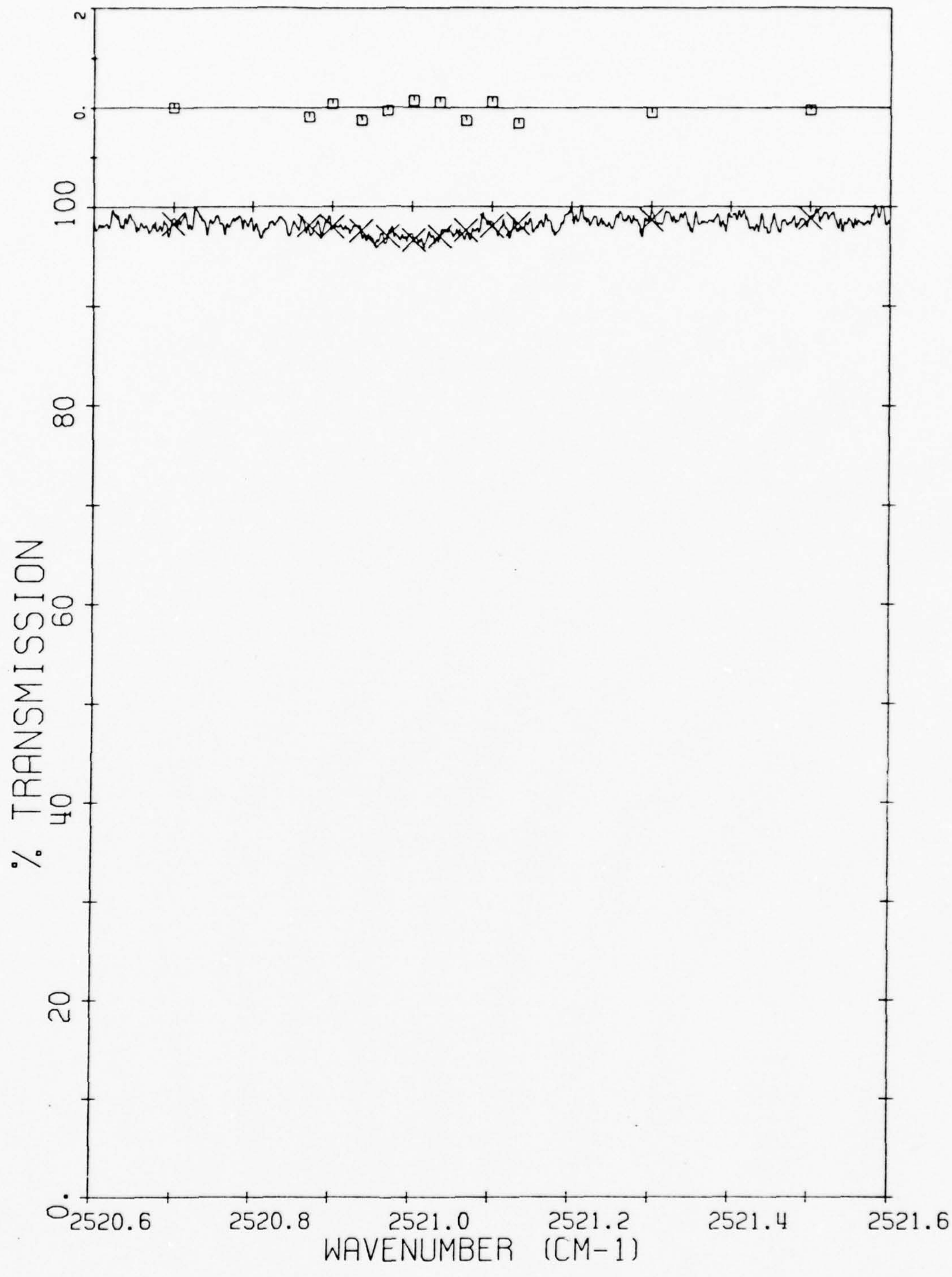


Figure 5. FITLINES Fit of a Weak Noisy Line

which provided the raw data is still active. When the checks to eliminate the possibilities of systematic errors are completed, it should be possible to improve the accuracy to 0.005 cm^{-1}. This is a reasonable number since the purely statistical standard deviation of the measured values was 0.002 cm^{-1}, which leads to a statistical error of the mean of ($\sqrt{4} = 2$) of 0.001 cm^{-1}.

3.4 Relative DF Laser -- HDO Absorption Line Wavenumbers

The relative wavenumbers of HDO absorption lines and DF laser lines have been determined from measured spectra. The results are given in Table 3. As discussed in Section 3.3, the current accuracy is 0.015 cm^{-1}. In most cases the separation between the laser line and the HDO line is such that this accuracy will have a negligible effect on the calculated laser absorption. However, for a few HDO lines [2727.260@P_2(4), 2704.080@P_2(5), 2594.233@P_3(6) and 2717.456@P_1(8)] this level of accuracy will lead to some uncertainty in the calculated absorption at the laser lines. The improvement in accuracy discussed in Section 3.3, should eliminate this problem.

3.5 HDO Absorption Line Widths and Strengths

HDO absorption line widths and strengths have been determined from measured spectra. The results are given in Table 4. Many of these parameters have been extracted from overlapped lines which were previously thought impossible to measure. Thus, while it is thought that the parameters are accurate to 10%, there is the possibility that in some cases parameters hace been included for lines which were too badly overlapped to yield parameters to this accuracy. Only time and experience can provide assurance that reasonable accuracy estimates are given when this procedure is used. Comparisons with the AFGL values [10] have been postponed until the measurements contract final report. This will allow the latest version of the data tape to be used.

Table 3.
HDO Absorption Line Positions
Relative to DF Laser Lines

Laser Line		Wavenumber (cm^{-1})	Relative Wavenumber (cm^{-1})
		AFCRL	Absorption Line - Laser Line
1-0	P(4)	2816.989	0.6238
		2816.757	0.3843
		2816.219	-0.1547
		2815.957	-0.4134
		2815.712	-0.6613
		2815.185	-1.1874
		2814.993	-1.3785
1-0	P(5)	2792.973	0.5507
		2792.595	0.1725
		2791.759	-0.6674
		2791.390	-1.0302
		2790.917	-1.5086
1-0	P(6)	2768.634	0.6771
		2767.574	-0.3828
		2767.277	-0.6847
		2766.506	-1.4519

Table 3 (Continued)
HDO Absorption Line Positions
Relative to DF Laser Lines

Laser Line		Wavenumber (cm^{-1})	Relative Wavenumber (cm^{-1})
		AFCRL	Absorption Line - Laser Line
2-1	P(3)	2751. 342	1. 2595
		2750. 503	0. 4203
		2749. 920	-0. 1637
1-0	P(7)	2744. 288	1. 2972
		2744. 147	1. 1596
		2743. 941	0. 9516
		2743. 576	0. 5885
		2742. 366	-0. 6235
2-1	P(4)	2728. 060	0. 7595
		2727. 870	0. 5701
		2727. 528	0. 2290
		2727. 260	-0. 0409
		2727. 092	-0. 2062
		2726. 625	-0. 6750
		2726. 161	-1. 1377
		2725. 682	-1. 6176

Table 3 (Continued)
HDO Absorption Line Positions
Relative to DF Laser Lines

Laser Line		Wavenumber (cm^{-1})	Relative Wavenumber (cm^{-1})
		AFCRL	Absorption Line - Laser Line
1-0	P(8)	2719.116	1.5825
		2718.774	1.2406
		2718.549	1.0183
		2717.751	0.2155
		2717.456	-0.0763
		2717.189	-0.3444
		2717.136	-0.3972
		2716.913	-0.6140
		2716.810	-0.7225
		2716.271	-1.2574
2-1	P(5)	2705.513	1.5254
		2704.458	0.4686
		2704.256	0.2668
		2704.080	0.0823
		2703.329	-0.6621
		2703.093	-0.8931
1-0	P(9)	2692.750	1.1493

Table 3 (Continued)
HDO Absorption Line Positions
Relative to DF Laser Lines

Laser Line		Wavenumber (cm^{-1})	Relative Wavenumber (cm^{-1})
		AFCRL	Absorption Line - Laser Line
2-1	P(6)	2681. 052	0. 8809
		2679. 215	-0. 9521
		2678. 702	-1. 4633
1-0	P(10)	2666. 295	1. 0878
		2664. 799	-0. 4075
		2664. 446	-0. 7598
2-1	P(7)	2657. 330	1. 4783
		2655. 746	-0. 1106
		2755. 459	-0. 3921
1-0	P(11)	2639. 660	1. 2675
		2638. 728	0. 3520
		2638. 557	0. 1817
		2638. 153	-0. 2251
		2637. 743	-0. 6315
		2637. 554	-0. 8230
		2637. 359	-1. 0155

Table 3 (Continued)
HDO Absorption Line Positions
Relative to DF Laser Lines

Laser Line		Wavenumber (cm^{-1})	Relative Wavenumber (cm^{-1})
		AFCRL	Absorption Line - Laser Line
2-1	P(8)	2632.414	1.3556
		2632.125	1.0688
		2629.845	-1.2113
		2629.715	-1.3446
3-2	P(5)	2617.726	0.3505
2-1	P(9)	2607.194	1.3970
		2606.935	1.1372
		2606.517	0.7145
		2606.311	0.5160
		2605.999	0.2007
		2605.183	-0.6125
		2604.668	-1.1279
		2604.440	-1.3534
3-2	P(6)	2594.905	0.7260
		2594.223	0.0307
		2593.980	-0.2013
		2593.618	-0.5646
		2593.261	-0.9401
		2592.882	-1.3055

Table 3 (Continued)
HDO Absorption Line Positions
Relative to DF Laser Lines

Laser Line		Wavenumber (cm^{-1})	Relative Wavenumber (cm^{-1})
		AFCRL	Absorption Line - Laser Line
2-1	P(10)	2581.046	0.9618
		2579.837	-0.2525
		2579.747	-0.3464
		2578.807	-1.2763
3-2	P(7)	2571.440	0.9280
		2571.237	0.7210
		2571.162	0.6477
		2570.381	-0.1363
		2570.140	-0.3704
		2569.961	-0.5480
		2569.302	-1.2070
2-1	P(11)	2553.110	-0.8330
		2552.787	-1.1553
3-2	P(8)	2546.993	0.6291
2-1	P(12)	2527.189	-0.1940
3-2	P(9)	2522.407	0.6500
		2521.006	-0.7465

Table 3 (Continued)
HDO Absorption Line Positions
Relative to DF Laser Lines

Laser Line		Wavenumber (cm^{-1})	Relative Wavenumber (cm^{-1})
		AFCRL	Absorption Line - Laser Line
2-1	P(13)	2501.461	1.0427
		2499.768	-0.6495
3-2	P(10)	2497.938	1.2274
		2495.666	-1.0337

Table 4.

HDO Absorption Line Widths and Strengths

Laser Line (cm $^{-1}$ μm)	AFCRL HDO Line (cm^{-1})	S $\left(10^{-23} \frac{cm^{-1}}{mol. cm^2}\right)$	γ (cm^{-1})
$P_3(11)$ 2471.2446 4.0465	2453.008	.0021 ± 25%	.1049 ± 25%
	2460.926	.0022 ± 100%	.0415 ± 100%
	2467.995	.0014 ± 25%	.0813 ± 25%
	2469.810	.0058 ± 30%	.0560 ± 30%
$P_3(10)$ 2496.7219 4.0053; $P_2(13)$ 2500.4297 3.9993	2497.938	.0025	.0758
	2497.263	.0042	.0946
	2499.768	.0054	.0698
$P_3(9)$ 2521.7692 3.9655	2522.407	.0011	.0721
	2524.464	.0205	.0886
$P_2(12)$ 2527.3869 3.9567	2527.189	.0014	.0933
$P_3(8)$ 2546.3745 3.9272	2539.273	.0232	.0750
	2544.668	.0415	.0866
	2546.993	.0567	.0862
	2547.822	.0415	.0727
	2548.663	.0308	.0479
	2548.720	.0472	.0517
	2549.907	.0402	.0678
	2550.507	.0245	.0813
$P_2(11)$ 2553.9539 3.9155	2553.110	.0250	.0771

Table 4 (Continued)

Laser Line	AFCRL HDO Line (cm^{-1})	S $\left(10^{-23} \frac{cm^{-1}}{mol. cm^2}\right)$	γ (cm^{-1})
$P_3(7)$	2570.140	.0232 ± 50%	.0907 ± 50%
2570.5231	2571.440	.0232 ± 50%	.0509 ± 50%
3.8903	2573.520	.0853	.0845
	2576.664	.1498	.0890
	2578.606	.1378	.0695
$P_2(10)$	2578.807	.1410	.0698
2580.1021	2581.046	.1372	.0797
3.8758	2582.303	.1896	.0915
	2585.437	.1319	.0889
	2590.826	.1348	.0847
$P_3(6)$	2591.220	.2479	.0913
2594.2009	2593.244	.2317	.0767
3.8548	2593.618	.2291	.0759
	2596.738	.2197	.0849
$P_2(9)$			
2605.8080	2605.183	.1923	.0917
3.8376	2606.311	.3733	.0927
	2619.762	.4171	.0951
$P_3(5)$	2621.733	.5202	.0852
2617.3888	2622.108	.5575	.0987
3.8206	2622.860	.5069	.0887
$P_2(8)$ 2631.0667 3.8007; $P_1(11)$ 2638.3943 3.7902; $P_3(4)$ 2640.0749 3.7877	2628.459	.4540	.0965
	2635.600	.6658 ± 20%	.0940 ± 20%
	2637.359	.6654 ± 20%	.0937 ± 20%
	2638.557	.7121 ± 20%	.0929 ± 20%
	2638.728	.4964 ± 20%	.0880 ± 20%
	2640.019	.0117	.0727
	2641.994	.2547	.0868

Table 4 (Continued)

Laser Line	AFCRL HDO Line (cm^{-1})	$S\left(10^{-23}\ \frac{cm^{-1}}{mol.\ cm^2}\right)$	γ (cm^{-1})
$P_2(7)$ 2655.8605 3.7653	2655.459	.7711	.1010
	2657.330	.5215	.0989
$P_1(10)$ 2665.2172 3.7520	2660.518	.5577	.1053
	2663.293	.9089	.1030
	2664.799	.0252 ± 30%	.1050 ± 30%
	2666.295	.8238	.0980
$P_2(6)$ 2680.1732 3.7311	2680.759	.8344 ± 20%	.1060 ± 30%
$P_1(9)$ 2691.6087 3.7153	2689.785	.4449	.1056
	2692.750	.7516	.1126
	2693.495	.0293 ± 25%	.0788 ± 25%
	2695.208	.4995	.1046
$P_2(5)$ 2703.9983 3.6982	2702.157	.0867	.1028
	2703.093	.0299	.1075
$P_2(4)$ 2727.3116 3.6666	2725.687	.2556	.1083
	2726.161	.5261	.1038
	2727.092	.0043 ± 30%	.0616 ± 30%
	2727.528	.0085 ± 30%	.0914 ± 30%
	2727.870	.0074 ± 30%	.0705 ± 30%
	2728.060	.0312	.1095
$P_1(7)$ 2742.9994 3.6456	2738.923	.4329 ± 20%	.1135 ± 20%
	2743.576	.0106 ± 30%	.1008 ± 30%
	2743.941	.0918 ± 30%	.1186 ± 30%

Table 4 (Continued)

Laser Line	AFCRL HDO Line (cm^{-1})	$S\left(10^{-23}\ \frac{cm^{-1}}{mol.\ cm^2}\right)$	γ (cm^{-1})
	2747.412	.1150 ± 50%	.1125 ± 50%
$P_3(3)$	2749.920	.0334 ± 50%	.1137 ± 50%
2750.0962	2750.503	.0278 ± 50%	.1070 ± 50%
3.6362	2751.342	.5032 ± 50%	.1072 ± 50%
	2753.545	.7728 ± 50%	.1121 ± 50%
	2756.558	.5171 ± 50%	.1080 ± 50%
$P_1(6)$	2764.551	.7902 ± 25%	.1024 ± 25%
2767.9677	2767.277	.9160 ± 25%	.1052 ± 25%
3.6128	2768.634	.3951 ± 25%	.1015 ± 25%
	2769.897	.4237 ± 25%	.1066 ± 25%
$P_2(2)$			
2772.342	2772.259	.7660 ± 25%	.1062 ± 25%
3.6071			
$P_1(5)$	2789.593	.8775 ± 25%	.0986 ± 25%
2792.4362	2791.759	.8568 ± 25%	.1004 ± 25%
3.5811			
$P_1(4)$	2814.993	.5374	.1000
2816.3794	2816.989	.4069	.0956
3.5507			

These strengths are per molecule of H_2O; that is, they are reduced by the nominal value of the HDO natural abundance (the same units as used on the data type).

4.0 ATMOSPHERIC TRANSMISSION CALCULATIONS

Fully resolved atmospheric molecular absorption has been calculated and plotted for all wavenumbers in the DF laser region (2480-2800 cm^{-1}) and the CO laser region (1900-2200 cm^{-1}). The calculations and plots were made using existing SAI computer codes which were rewritten and combined into a single program (SYNSPC). This reduced the size and cost of the codes, while simultaneously increasing the ease of operation. SYNSPC uses a modified version of the AFGL line parameter tape [10] and includes all the molecules available on the tape. It includes models of the water continuum, the nitrogen continuum, and the effect of water self broadening. The calculations can be performed for arbitrary values of temperature, pressure (altitude), humidity, concentration of absorbing atmospheric gasses, and aerosol extinction.

4.1 Physics of SYNSPC

The basic line-by-line approach has been used with some additional sophistication to increase the speed and accuracy of the calculations. The line-by-line calculations of the atmospheric transmission are made according to the following expressions.

$$k_j(\bar{\nu}) = \sum_i \frac{S_i \gamma_i}{\pi[(\bar{\nu}-\bar{\nu}_i)^2 + \gamma_i^2]}$$

$$T = e^{-\sum_j N_j k_j(\bar{\nu})} \times e^{-k_s} \times e^{-k(\bar{\nu})_{cont}}$$

$$Q = Q_r Q_v$$

or

$$\frac{Q(296^oK)}{Q(T)} = \frac{Q_r(296^oK)Q_v(296^oK)}{Q_r(T)Q_v(T)}$$

where Q_r is the rotational partition function and Q_v is the vibrational partition function. The expressions used for the partition functions are:

$$\frac{Q_r(296^oK)}{Q_r(T)} = \left(\frac{296^oK}{T}\right)^j \quad \text{where } j = \begin{cases} 1 & \text{Linear Molecule} \\ 3/2 & \text{Nonlinear Molecule} \end{cases}$$

Linear Molecules: CO_2, N_2O, CO, O_2

Nonlinear Molecules: H_2O, HDO, O_3, CH_4

$$\frac{Q_v(296^oK)}{Q_v(T)} = \frac{\pi_i\left(1-e^{-\omega_i \times 1.4388/296}\right)^{-d_i}}{\pi_i\left(1-e^{-\omega_i \times 1.4388/T}\right)^{-d_i}}$$

where d_i and ω_i are the degeneracy and wavenumber of normal mode i.

The integrated molecular number densities along the path are calculated by:

$$N = \frac{6.02257 \times 10^{23}}{22.415} \times \frac{273.16}{T} P_t P_a L \times 10^{-4}$$

where

T = Temperature

P_t = Total air pressure in atmospheres

P_a = Partial pressure of absorbing molecules in parts per million

L = Path length in kilometers

$k_j(\bar{\nu})$ = Absorption coefficient for molecule j at wavenumber $\bar{\nu}$

T = Transmission

$\bar{\nu}$ = Observation wavenumber

$\bar{\nu}_i$ = Absorption line wavenumber for line i

γ_i = Absorption line width for line i of molecule j

S_i = Absorption line strength for line i of molecule j

N_j = Number of absorbing molecules per cm^2 in path for molecule j

k_s = Aerosol extinction coefficient entered by user

$k(\bar{\nu})_{cont}$ = Nitrogen and H_2O continuum

Empirical models based on the Burch measurements [3, 4, 13] of the nitrogen and water continua are included in $k(\bar{\nu})_{cont}$. The water continuum covers the regions (2400-2850 cm^{-1}) [4], and (800-1200 cm^{-1}) [13]. The nitrogen continuum covers the region (2389-2648 cm^{-1}) [3]. A provision is made for the user to enter the aerosol extinction coefficient k_s.

The temperature dependence of the line strength is calculated using the Boltzman factor and the vibrational and rotational partitions functions. Thus:

$$S_{ij} = S_{ij}(296^oK) \times \frac{Q_j(296^oK)}{Q_j(T)} \; e^{1.4388 E''_{ij} \frac{(T-296^oK)}{T(296^oK)}}$$

where Q_j is the partition function, E''_{ij} is the initial state energy, and T is the temperature. i represents the transition identification, and j represents the molecular species identification. The value of Q_j depends on the temperature and species of the molecule, while E''_{ij} depends only on the particular molecule and transition involved.

4.2 Calculated Atmospheric Absorption in the DF and CO Laser Regions (2480 cm^{-1} to 2800 cm^{-1}) and (1900 cm^{-1} to 2200 cm^{-1})

The atmospheric molecular absorption has been calculated for a number of different conditions in the DF laser region. The absorption has also been calculated in the CO laser region for a nominal set of conditions.

Figure 6 gives the monochromatic atmospheric molecular absorption line transmission, without the continuum, in the 2480 - 2800 cm^{-1} region for a 5 kilometer path and midlatitude sea level conditions. Figure 7 is identical except a 0.1 cm^{-1} trapezoidal instrument spectral response function is used to simulate the atmospheric transmission as it would be observed by an interferometer. Figure 8 gives the absorption coefficient for the previous conditions. Figure 9 includes the Burch water and nitrogen continua, the instrument spectral response function, and is done for conditions which correspond to one of the measurements made by NRL. The calculated atmospheric transmission for a 16 km path is given in Figure 10 for infinite resolution, and in Figure 11 for 0.08 cm^{-1} resolution. In both cases the Burch continua are included.

The absorption calculated between 1900 and 2200 cm^{-1} in the CO laser region is given in Figures 12 and 13. For these CO calculations, the parameters from the January 1976 AFCRL data tape were used without change. Recent measurements by Chang [11] give values for the H_2O line strengths in the CO region which are typically 10% to 20% stronger than the AFGL values. In individual cases the measured strengths are a factor of two stronger. Dr. Chang [12] indicates that the final calibration of his data may well eliminate the 10% to 20% differences. Thus it would appear that the strengths of most of the very strong lines on the data tape are accurate. However, these measurements were only made for a few of the very strong lines and do not include the many weak lines which are so important in the more transparent intervals.

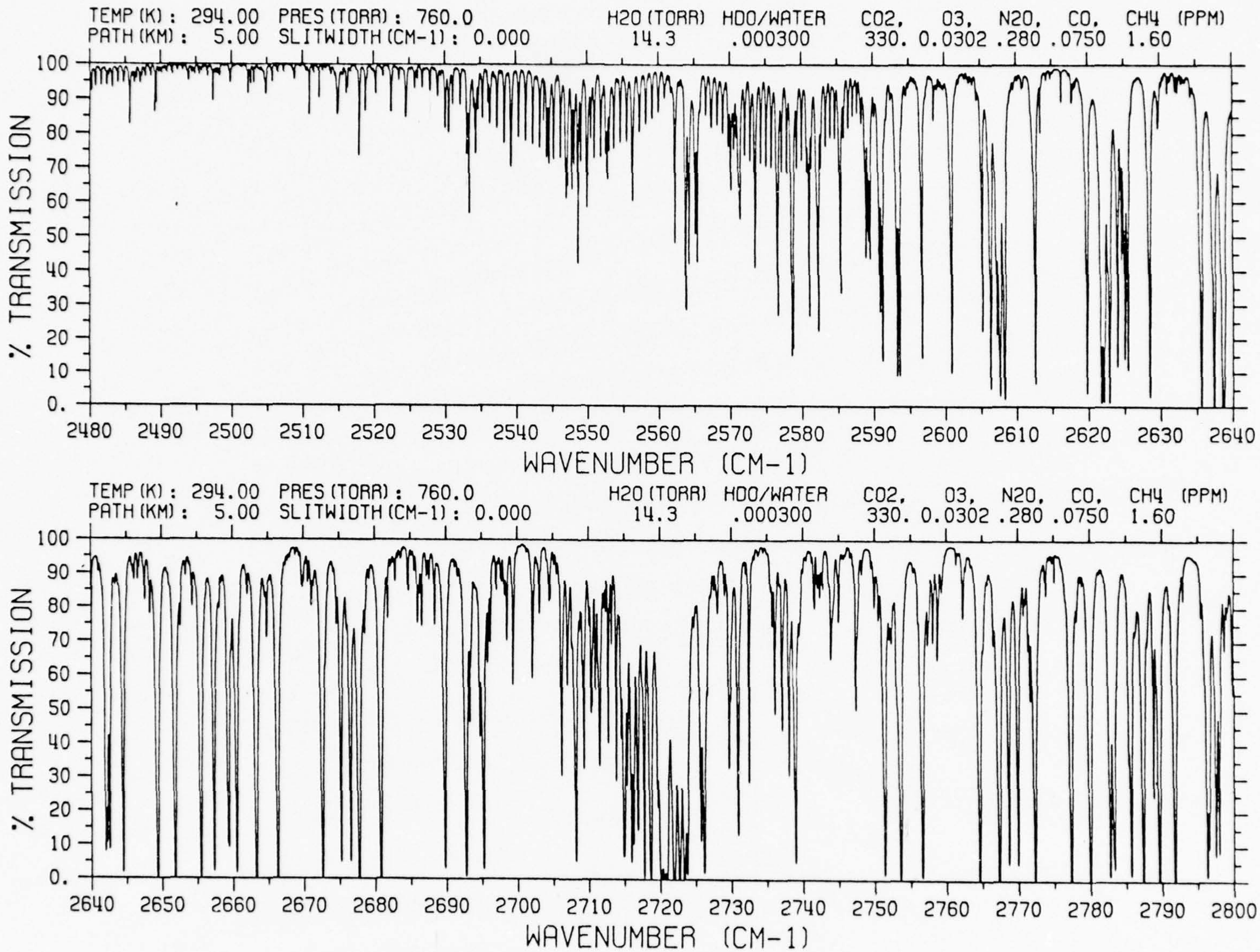


Figure 6. Atmospheric Molecular Line Transmission -- No Continuum

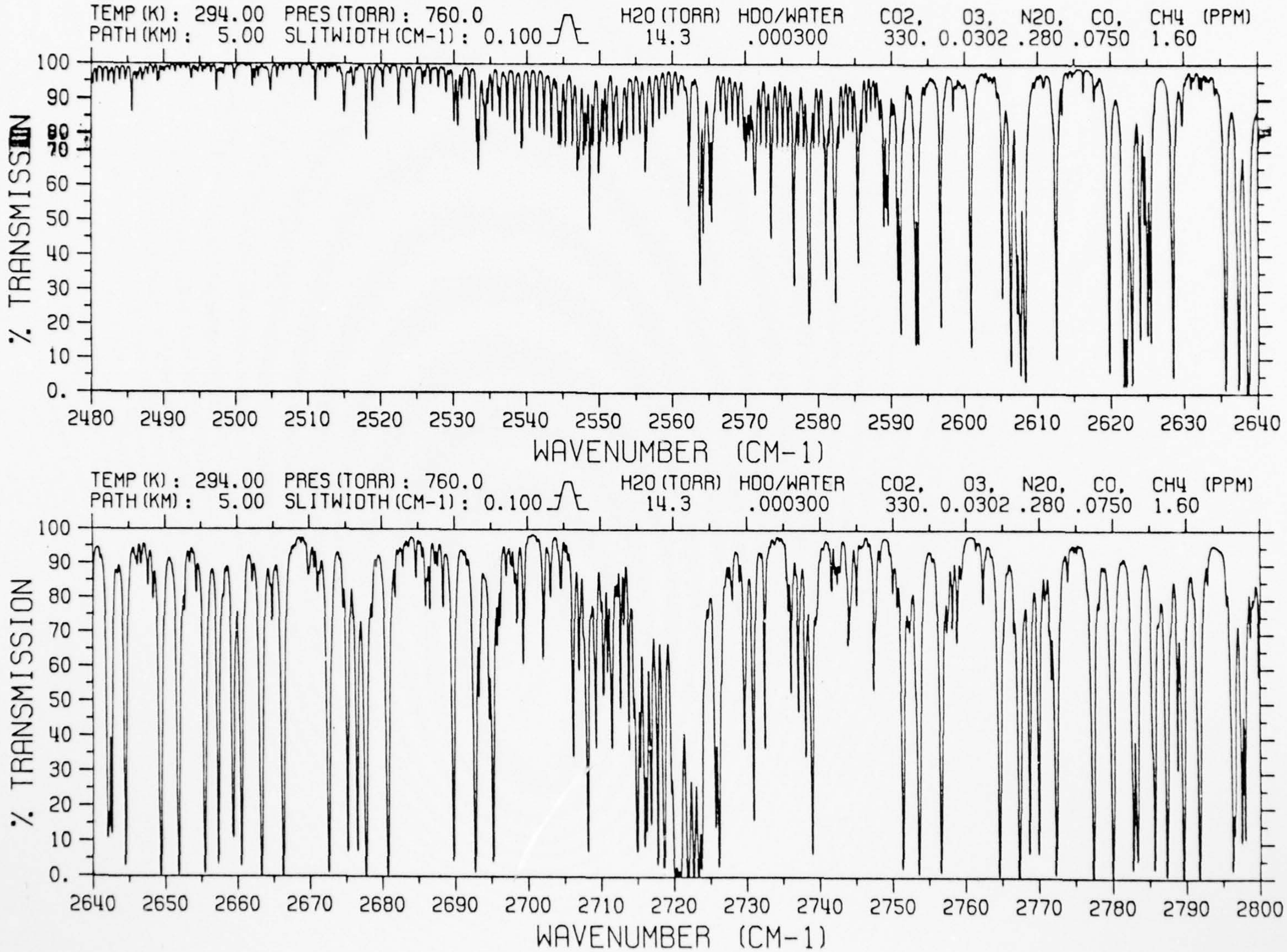


Figure 7. Calculated Atmospheric Molecular Line Transmission as it would be Observed with 0.1 cm^{-1} Resolution -- No Continuum

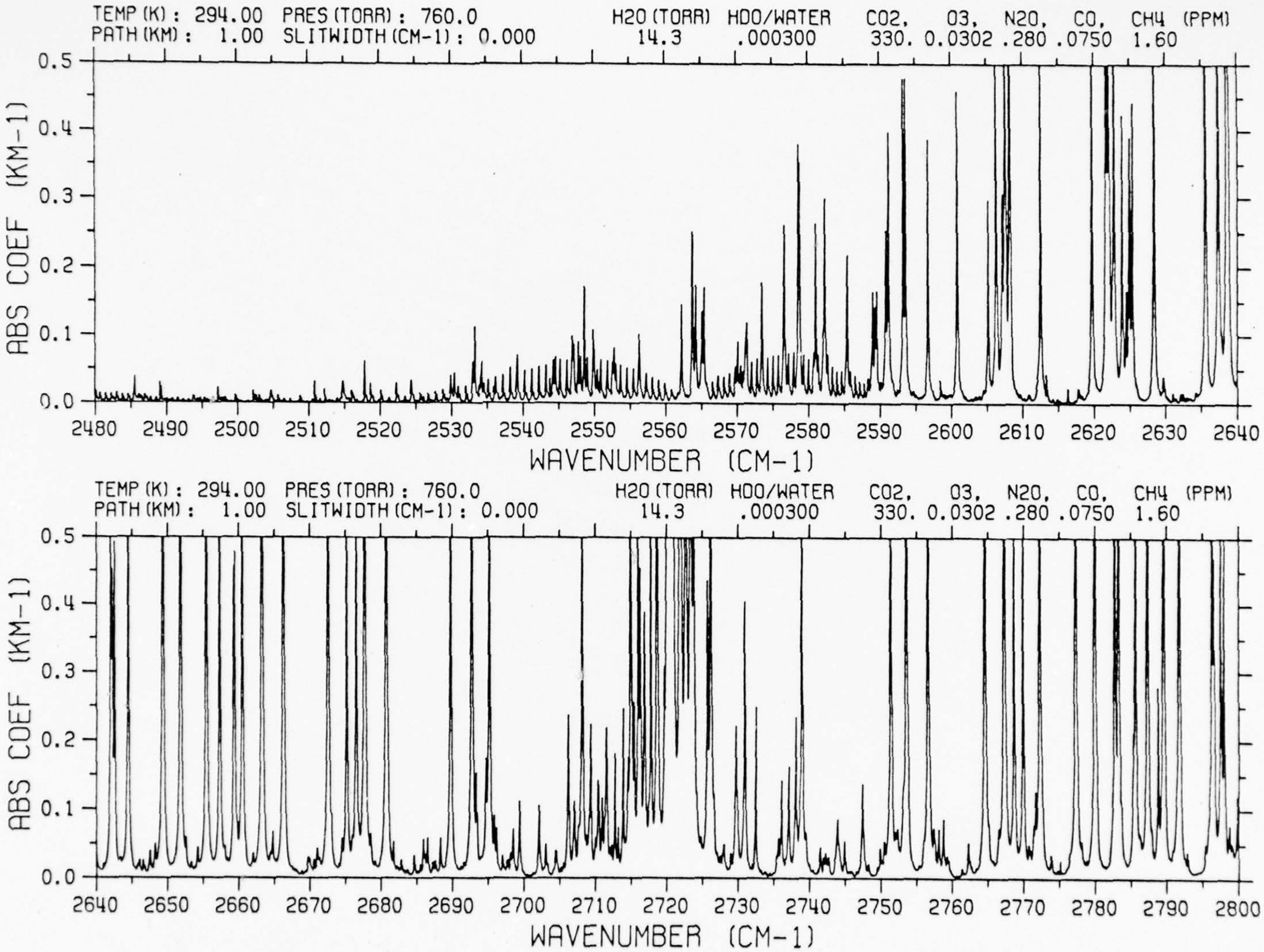


Figure 8. Atmospheric Molecular Line Absorption Coefficient -- No Continuum

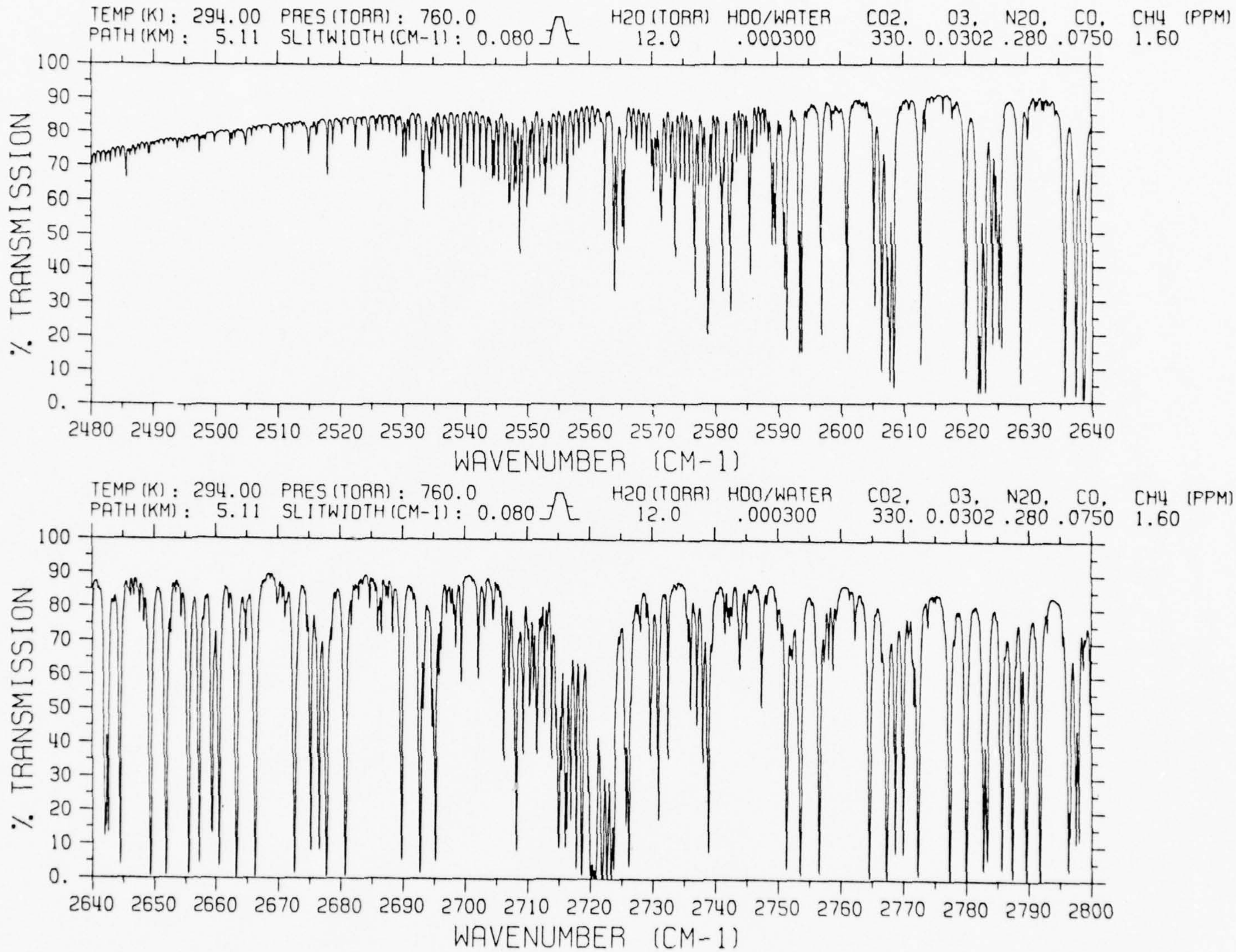


Figure 9. Atmospheric Molecular Transmission as it would be Observed by NRL -- with Burch Continua

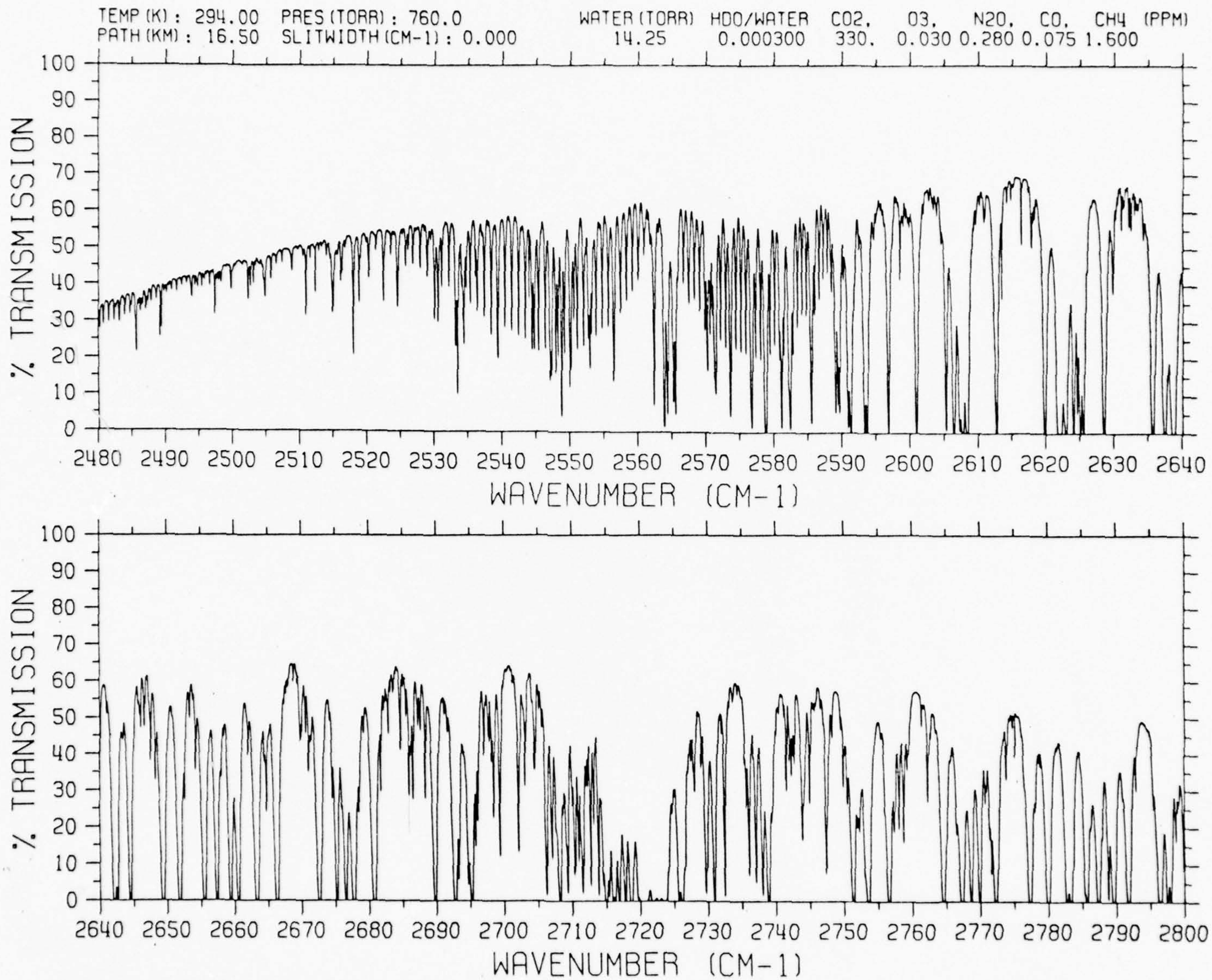


Figure 10. Atmospheric Molecular Transmission for a 16 km Path -- with Burch Continua

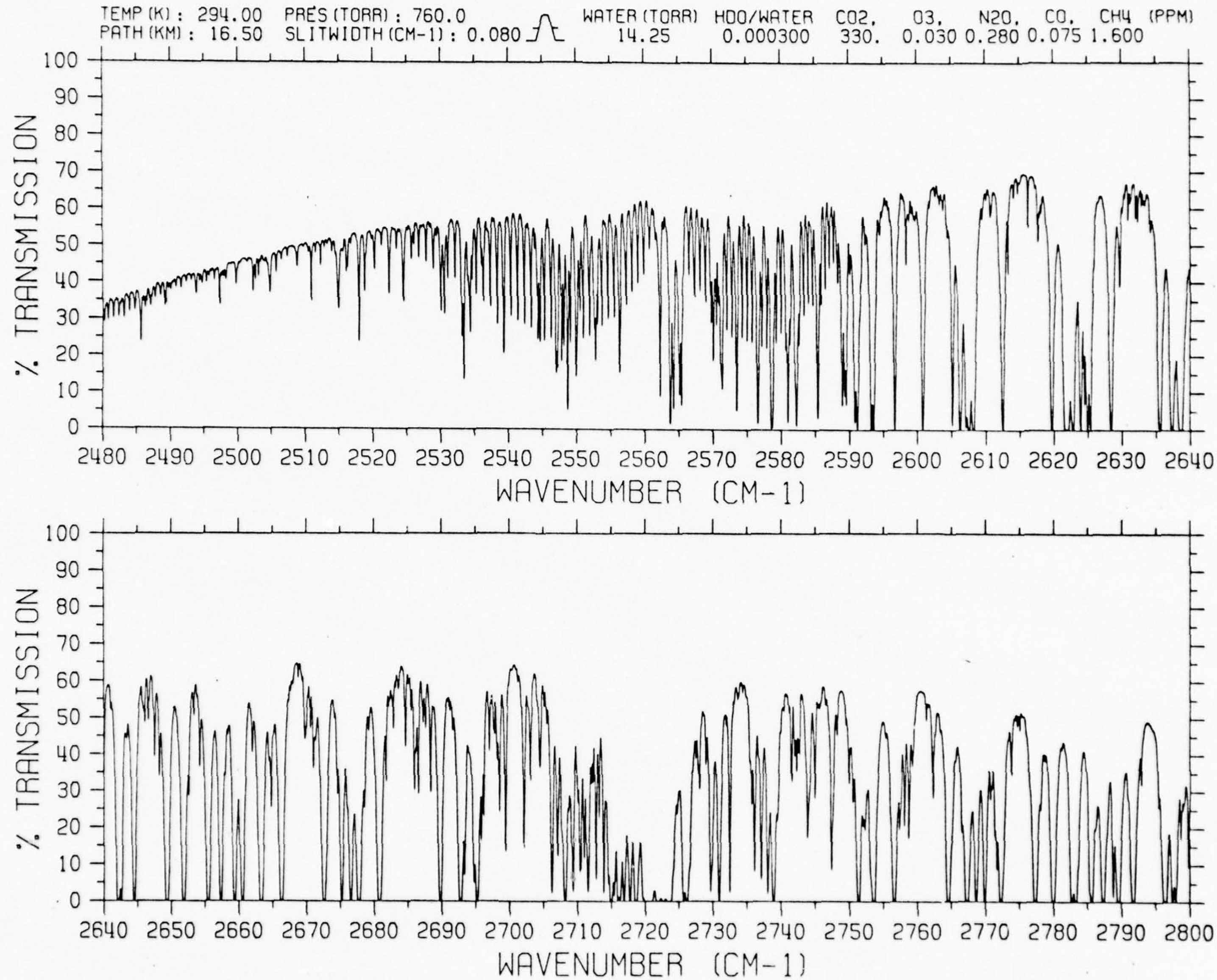


Figure 11. Atmospheric Molecular Transmission for a 16 km Path as it would be Observed with 0.08 cm^{-1} Resolution -- with Burch Continua

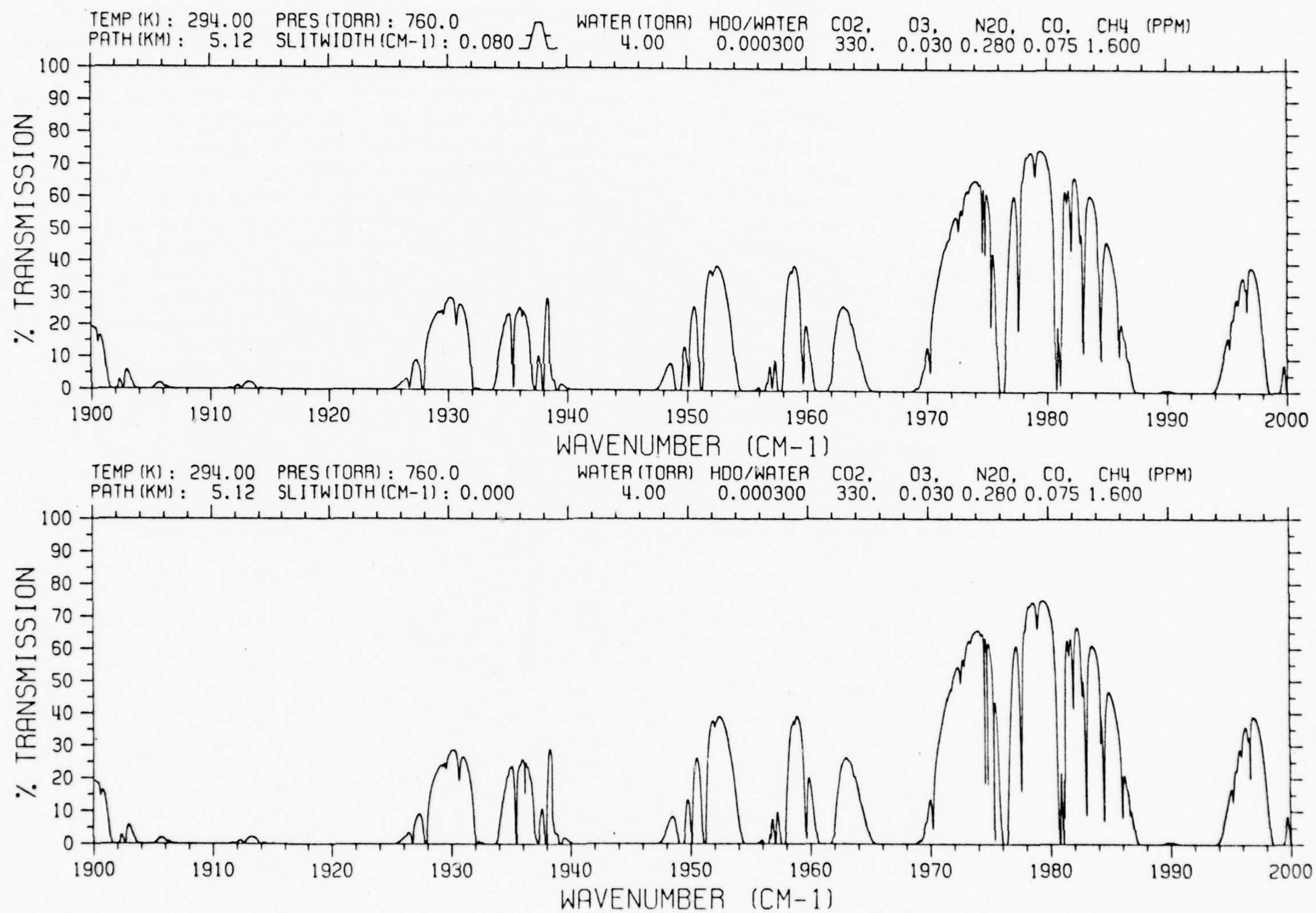


Figure 12. Atmospheric Molecular Line Transmission in the CO Laser Region

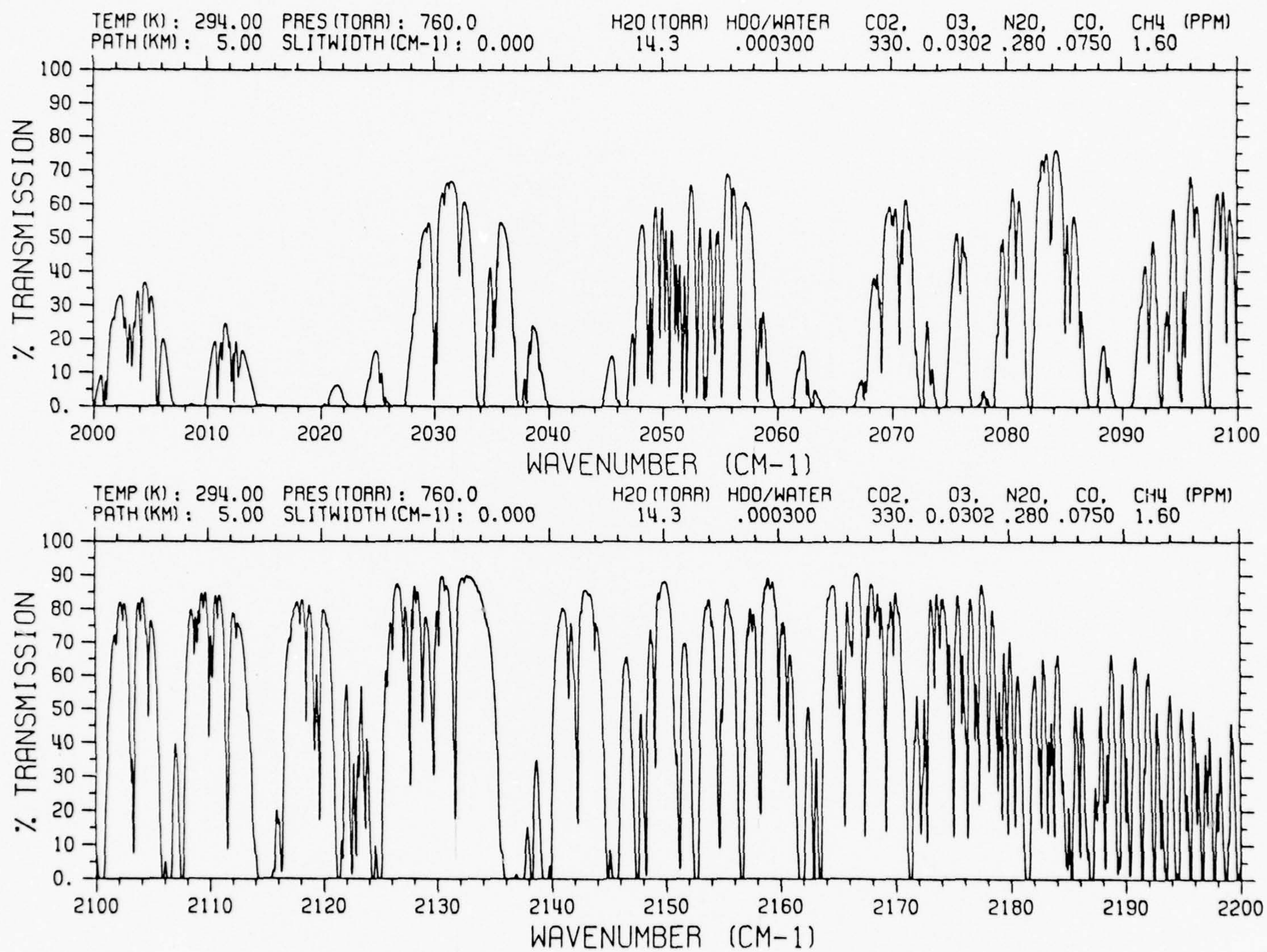


Figure 13. Atmospheric Molecular Line Transmission in the CO Laser Region

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APPENDIX A

DF LASER ATMOSPHERIC ABSORPTION COEFFICIENTS AS A FUNCTION OF TEMPERATURE AND WATER VAPOR PARTIAL PRESSURE

DF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P1(5)	2792.4338	50					
			0	0.0	0.0	1.452E-03	1.452E-03
			5	1.286E-02	0.0	1.302E-02	2.588E-02
			8	2.113E-02	0.0	2.023E-02	4.136E-02
			12	3.279E-02	0.0	3.016E-02	6.295E-02
			15	4.203E-02	0.0	3.783E-02	7.985E-02
			20	5.832E-02	0.0	5.105E-02	1.094E-01
		70					
			0	0.0	0.0	1.444E-03	1.444E-03
			5	1.084E-02	0.0	1.318E-02	2.402E-02
			8	1.782E-02	0.0	2.051E-02	3.833E-02
			12	2.770E-02	0.0	3.060E-02	5.830E-02
			15	3.553E-02	0.0	3.841E-02	7.394E-02
			20	4.937E-02	0.0	5.189E-02	1.013E-01
		90					
			0	0.0	0.0	1.439E-03	1.439E-03
			5	9.248E-03	0.0	1.333E-02	2.258E-02
			8	1.523E-02	0.0	2.077E-02	3.599E-02
			12	2.369E-02	0.0	3.102E-02	5.471E-02
			15	3.041E-02	0.0	3.896E-02	6.937E-02
			20	4.232E-02	0.0	5.268E-02	9.500E-02
P1(4)	2816.3845	50					
			0	0.0	0.0	3.958E-03	3.958E-03
			5	1.389E-02	0.0	2.307E-02	3.696E-02
			8	2.282E-02	0.0	3.467E-02	5.749E-02
			12	3.542E-02	0.0	5.030E-02	8.572E-02
			15	4.539E-02	0.0	6.213E-02	1.075E-01
			20	6.300E-02	0.0	8.207E-02	1.451E-01
		70					
			0	0.0	0.0	3.841E-03	3.841E-03
			5	1.166E-02	0.0	2.455E-02	3.621E-02
			8	1.918E-02	0.0	3.712E-02	5.630E-02
			12	2.981E-02	0.0	5.403E-02	8.383E-02
			15	3.823E-02	0.0	6.683E-02	1.051E-01
			20	5.312E-02	0.0	8.837E-02	1.415E-01
		90					
			0	0.0	0.0	3.729E-03	3.729E-03
			5	9.916E-03	0.0	2.610E-02	3.602E-02
			8	1.633E-02	0.0	3.966E-02	5.599E-02
			12	2.540E-02	0.0	5.790E-02	8.331E-02
			15	3.261E-02	0.0	7.170E-02	1.043E-01
			20	4.538E-02	0.0	9.491E-02	1.403E-01

IR ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

IR LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P3(10)	2496.7219	50					
			0	0.0	2.649E-02	5.083E-04	2.700E-02
			5	8.842E-03	2.649E-02	7.541E-04	3.608E-02
			8	1.453E-02	2.649E-02	9.078E-04	4.192E-02
			12	2.255E-02	2.649E-02	1.120E-03	5.016E-02
			15	2.890E-02	2.649E-02	1.284E-03	5.667E-02
			20	4.011E-02	2.649E-02	1.567E-03	6.816E-02
		70					
			0	0.0	2.587E-02	5.507E-04	2.642E-02
			5	7.558E-03	2.587E-02	8.601E-04	3.429E-02
			8	1.243E-02	2.587E-02	1.054E-03	3.936E-02
			12	1.932E-02	2.587E-02	1.321E-03	4.651E-02
			15	2.478E-02	2.587E-02	1.529E-03	5.218E-02
			20	3.443E-02	2.587E-02	1.887E-03	6.219E-02
		90					
			0	0.0	2.532E-02	5.940E-04	2.591E-02
			5	6.535E-03	2.532E-02	9.773E-04	3.283E-02
			8	1.076E-02	2.532E-02	1.218E-03	3.729E-02
			12	1.674E-02	2.532E-02	1.550E-03	4.361E-02
			15	2.149E-02	2.532E-02	1.808E-03	4.861E-02
			20	2.990E-02	2.532E-02	2.255E-03	5.747E-02
P2(13)	2500.4297	50					
			0	0.0	2.434E-02	4.466E-04	2.479E-02
			5	8.692E-03	2.434E-02	4.784E-04	3.351E-02
			8	1.428E-02	2.434E-02	4.983E-04	3.912E-02
			12	2.217E-02	2.434E-02	5.256E-04	4.703E-02
			15	2.841E-02	2.434E-02	5.467E-04	5.329E-02
			20	3.943E-02	2.434E-02	5.832E-04	6.435E-02
		70					
			0	0.0	2.379E-02	4.978E-04	2.429E-02
			5	7.434E-03	2.379E-02	5.408E-04	3.177E-02
			8	1.223E-02	2.379E-02	5.676E-04	3.659E-02
			12	1.900E-02	2.379E-02	6.046E-04	4.340E-02
			15	2.437E-02	2.379E-02	6.333E-04	4.880E-02
			20	3.387E-02	2.379E-02	6.828E-04	5.834E-02
		90					
			0	0.0	2.330E-02	5.507E-04	2.385E-02
			5	6.432E-03	2.330E-02	6.083E-04	3.034E-02
			8	1.059E-02	2.330E-02	6.442E-04	3.453E-02
			12	1.648E-02	2.330E-02	6.939E-04	4.047E-02
			15	2.115E-02	2.330E-02	7.323E-04	4.518E-02
			20	2.943E-02	2.330E-02	7.989E-04	5.353E-02

IR ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P3(9)	2521.7693	50					
			0	0.0	1.497E-02	4.979E-04	1.547E-02
			5	7.791E-03	1.497E-02	5.562E-04	2.332E-02
			8	1.280E-02	1.497E-02	5.925E-04	2.837E-02
			12	1.987E-02	1.497E-02	6.426E-04	3.549E-02
			15	2.546E-02	1.497E-02	6.813E-04	4.112E-02
			20	3.534E-02	1.497E-02	7.482E-04	5.106E-02
		70					
			0	0.0	1.471E-02	5.526E-04	1.526E-02
			5	6.686E-03	1.471E-02	6.246E-04	2.202E-02
			8	1.100E-02	1.471E-02	6.696E-04	2.637E-02
			12	1.709E-02	1.471E-02	7.316E-04	3.253E-02
			15	2.192E-02	1.471E-02	7.796E-04	3.741E-02
			20	3.046E-02	1.471E-02	8.626E-04	4.603E-02
		90					
			0	0.0	1.447E-02	6.133E-04	1.508E-02
			5	5.803E-03	1.447E-02	7.011E-04	2.097E-02
			8	9.553E-03	1.447E-02	7.560E-04	2.478E-02
			12	1.487E-02	1.447E-02	8.319E-04	3.016E-02
			15	1.908E-02	1.447E-02	8.907E-04	3.444E-02
			20	2.655E-02	1.447E-02	9.924E-04	4.201E-02
P2(12)	2527.3870	50					
			0	0.0	1.321E-02	8.104E-04	1.402E-02
			5	7.591E-03	1.321E-02	9.043E-04	2.171E-02
			8	1.247E-02	1.321E-02	9.623E-04	2.665E-02
			12	1.936E-02	1.321E-02	1.041E-03	3.362E-02
			15	2.481E-02	1.321E-02	1.102E-03	3.913E-02
			20	3.443E-02	1.321E-02	1.205E-03	4.885E-02
		70					
			0	0.0	1.300E-02	8.442E-04	1.384E-02
			5	6.520E-03	1.300E-02	9.455E-04	2.046E-02
			8	1.072E-02	1.300E-02	1.008E-03	2.473E-02
			12	1.667E-02	1.300E-02	1.094E-03	3.076E-02
			15	2.138E-02	1.300E-02	1.160E-03	3.553E-02
			20	2.970E-02	1.300E-02	1.272E-03	4.397E-02
		90					
			0	0.0	1.280E-02	8.753E-04	1.368E-02
			5	5.663E-03	1.280E-02	9.846E-04	1.945E-02
			8	9.324E-03	1.280E-02	1.052E-03	2.318E-02
			12	1.451E-02	1.280E-02	1.145E-03	2.845E-02
			15	1.862E-02	1.280E-02	1.216E-03	3.264E-02
			20	2.591E-02	1.280E-02	1.338E-03	4.005E-02

OF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P3(12)	2445.3535	50					
			0	0.0	6.852E-02	5.913E-03	7.443E-02
			5	1.131E-02	6.852E-02	5.920E-03	8.576E-02
			8	1.859E-02	6.852E-02	5.924E-03	9.303E-02
			12	2.885E-02	6.852E-02	5.930E-03	1.033E-01
			15	3.697E-02	6.852E-02	5.935E-03	1.114E-01
			20	5.131E-02	6.852E-02	5.943E-03	1.258E-01
		70					
			0	0.0	6.616E-02	7.002E-03	7.316E-02
			5	9.590E-03	6.616E-02	7.013E-03	8.276E-02
			8	1.577E-02	6.616E-02	7.019E-03	8.895E-02
			12	2.451E-02	6.616E-02	7.028E-03	9.770E-02
			15	3.144E-02	6.616E-02	7.035E-03	1.046E-01
			20	4.369E-02	6.616E-02	7.047E-03	1.169E-01
		90					
			0	0.0	6.404E-02	8.244E-03	7.228E-02
			5	8.230E-03	6.404E-02	8.258E-03	8.052E-02
			8	1.355E-02	6.404E-02	8.268E-03	8.585E-02
			12	2.108E-02	6.404E-02	8.281E-03	9.340E-02
			15	2.706E-02	6.404E-02	8.290E-03	9.939E-02
			20	3.766E-02	6.404E-02	8.308E-03	1.100E-01
P3(11)	2471.2446	50					
			0	0.0	4.527E-02	5.424E-03	5.069E-02
			5	9.962E-03	4.527E-02	6.672E-03	6.191E-02
			8	1.637E-02	4.527E-02	7.442E-03	6.908E-02
			12	2.541E-02	4.527E-02	8.491E-03	7.917E-02
			15	3.256E-02	4.527E-02	9.294E-03	8.713E-02
			20	4.519E-02	4.527E-02	1.066E-02	1.011E-01
		70					
			0	0.0	4.397E-02	5.366E-03	4.934E-02
			5	8.481E-03	4.397E-02	6.888E-03	5.934E-02
			8	1.395E-02	4.397E-02	7.829E-03	6.574E-02
			12	2.168E-02	4.397E-02	9.112E-03	7.476E-02
			15	2.780E-02	4.397E-02	1.010E-02	8.187E-02
			20	3.864E-02	4.397E-02	1.177E-02	9.438E-02
		90					
			0	0.0	4.279E-02	5.322E-03	4.811E-02
			5	7.306E-03	4.279E-02	7.153E-03	5.725E-02
			8	1.203E-02	4.279E-02	8.287E-03	6.310E-02
			12	1.872E-02	4.279E-02	9.836E-03	7.134E-02
			15	2.403E-02	4.279E-02	1.103E-02	7.784E-02
			20	3.343E-02	4.279E-02	1.306E-02	8.928E-02

DF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P3(7)	2570.5227	50					
			0	0.0	5.183E-03	3.904E-02	4.422E-02
			5	6.556E-03	5.183E-03	4.030E-02	5.204E-02
			8	1.077E-02	5.183E-03	4.109E-02	5.705E-02
			12	1.672E-02	5.183E-03	4.218E-02	6.408E-02
			15	2.143E-02	5.183E-03	4.302E-02	6.963E-02
			20	2.974E-02	5.183E-03	4.446E-02	7.938E-02
		70					
			0	0.0	5.149E-03	3.769E-02	4.284E-02
			5	5.670E-03	5.149E-03	3.922E-02	5.004E-02
			8	9.326E-03	5.149E-03	4.017E-02	5.464E-02
			12	1.449E-02	5.149E-03	4.148E-02	6.112E-02
			15	1.859E-02	5.149E-03	4.249E-02	6.623E-02
			20	2.583E-02	5.149E-03	4.424E-02	7.522E-02
		90					
			0	0.0	5.117E-03	3.639E-02	4.151E-02
			5	4.956E-03	5.117E-03	3.821E-02	4.829E-02
			8	8.160E-03	5.117E-03	3.935E-02	5.262E-02
			12	1.270E-02	5.117E-03	4.091E-02	5.872E-02
			15	1.630E-02	5.117E-03	4.212E-02	6.354E-02
			20	2.268E-02	5.117E-03	4.420E-02	7.200E-02
P2(10)	2580.1021	50					
			0	0.0	4.288E-03	4.371E-02	4.800E-02
			5	6.446E-03	4.288E-03	4.450E-02	5.524E-02
			8	1.059E-02	4.288E-03	4.500E-02	5.988E-02
			12	1.644E-02	4.288E-03	4.567E-02	6.640E-02
			15	2.107E-02	4.288E-03	4.619E-02	7.155E-02
			20	2.924E-02	4.288E-03	4.708E-02	8.060E-02
		70					
			0	0.0	4.269E-03	4.337E-02	4.764E-02
			5	5.583E-03	4.269E-03	4.427E-02	5.412E-02
			8	9.183E-03	4.269E-03	4.483E-02	5.828E-02
			12	1.427E-02	4.269E-03	4.559E-02	6.413E-02
			15	1.830E-02	4.269E-03	4.618E-02	6.875E-02
			20	2.544E-02	4.269E-03	4.719E-02	7.690E-02
		90					
			0	0.0	4.251E-03	4.293E-02	4.718E-02
			5	4.888E-03	4.251E-03	4.394E-02	5.308E-02
			8	8.046E-03	4.251E-03	4.457E-02	5.687E-02
			12	1.252E-02	4.251E-03	4.543E-02	6.220E-02
			15	1.607E-02	4.251E-03	4.609E-02	6.641E-02
			20	2.237E-02	4.251E-03	4.723E-02	7.384E-02

DF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P3(6)	2594.2009	50					
			0	0.0	3.270E-03	2.434E-03	5.704E-03
			5	6.363E-03	3.270E-03	4.665E-03	1.430E-02
			8	1.045E-02	3.270E-03	6.046E-03	1.977E-02
			12	1.623E-02	3.270E-03	7.936E-03	2.743E-02
			15	2.080E-02	3.270E-03	9.391E-03	3.346E-02
			20	2.886E-02	3.270E-03	1.188E-02	4.401E-02
		70					
			0	0.0	3.265E-03	2.623E-03	5.888E-03
			5	5.523E-03	3.265E-03	5.171E-03	1.396E-02
			8	9.084E-03	3.265E-03	6.749E-03	1.910E-02
			12	1.412E-02	3.265E-03	8.910E-03	2.629E-02
			15	1.811E-02	3.265E-03	1.057E-02	3.195E-02
			20	2.516E-02	3.265E-03	1.343E-02	4.186E-02
		90					
			0	0.0	3.261E-03	2.806E-03	6.067E-03
			5	4.845E-03	3.261E-03	5.698E-03	1.380E-02
			8	7.977E-03	3.261E-03	7.490E-03	1.873E-02
			12	1.241E-02	3.261E-03	9.944E-03	2.562E-02
			15	1.593E-02	3.261E-03	1.183E-02	3.103E-02
			20	2.217E-02	3.261E-03	1.507E-02	4.051E-02
P2(9)	2605.8081	50					
			0	0.0	2.769E-03	1.779E-03	4.548E-03
			5	6.418E-03	2.769E-03	1.196E-02	2.114E-02
			8	1.054E-02	2.769E-03	1.807E-02	3.138E-02
			12	1.636E-02	2.769E-03	2.621E-02	4.534E-02
			15	2.096E-02	2.769E-03	3.232E-02	5.605E-02
			20	2.909E-02	2.769E-03	4.250E-02	7.435E-02
		70					
			0	0.0	2.664E-03	1.720E-03	4.384E-03
			5	5.571E-03	2.664E-03	1.216E-02	2.039E-02
			8	9.160E-03	2.664E-03	1.842E-02	3.024E-02
			12	1.423E-02	2.664E-03	2.676E-02	4.366E-02
			15	1.825E-02	2.664E-03	3.303E-02	5.394E-02
			20	2.536E-02	2.664E-03	4.345E-02	7.149E-02
		90					
			0	0.0	2.567E-03	1.679E-03	4.246E-03
			5	4.867E-03	2.567E-03	1.233E-02	1.978E-02
			8	8.042E-03	2.567E-03	1.872E-02	2.933E-02
			12	1.251E-02	2.567E-03	2.724E-02	4.232E-02
			15	1.606E-02	2.567E-03	3.364E-02	5.226E-02
			20	2.234E-02	2.567E-03	4.429E-02	6.920E-02

DF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P3(5)	2617.3885	50					
			0	0.0	2.139E-03	2.642E-04	2.403E-03
			5	6.656E-03	2.139E-03	1.026E-03	9.861E-03
			8	1.100E-02	2.139E-03	1.501E-03	1.464E-02
			12	1.708E-02	2.139E-03	2.155E-03	2.137E-02
			15	2.189E-02	2.139E-03	2.661E-03	2.669E-02
			20	3.037E-02	2.139E-03	3.533E-03	3.604E-02
		70					
			0	0.0	2.139E-03	2.579E-04	2.397E-03
			5	5.802E-03	2.139E-03	1.084E-03	9.026E-03
			8	9.543E-03	2.139E-03	1.600E-03	1.328E-02
			12	1.463E-02	2.139E-03	2.312E-03	1.928E-02
			15	1.902E-02	2.139E-03	2.862E-03	2.402E-02
			20	2.643E-02	2.139E-03	3.813E-03	3.239E-02
		90					
			0	0.0	2.139E-03	2.527E-04	2.392E-03
			5	5.081E-03	2.139E-03	1.145E-03	8.365E-03
			8	8.365E-03	2.139E-03	1.703E-03	1.221E-02
			12	1.302E-02	2.139E-03	2.473E-03	1.763E-02
			15	1.671E-02	2.139E-03	3.070E-03	2.192E-02
			20	2.325E-02	2.139E-03	4.101E-03	2.949E-02
P2(8)	2631.0667	50					
			0	0.0	1.674E-03	1.337E-03	3.011E-03
			5	6.997E-03	1.674E-03	5.561E-03	1.423E-02
			8	1.150E-02	1.674E-03	8.047E-03	2.122E-02
			12	1.785E-02	1.674E-03	1.131E-02	3.083E-02
			15	2.287E-02	1.674E-03	1.372E-02	3.826E-02
			20	3.174E-02	1.674E-03	1.767E-02	5.108E-02
		70					
			0	0.0	1.674E-03	1.328E-03	3.002E-03
			5	6.050E-03	1.674E-03	6.264E-03	1.399E-02
			8	9.950E-03	1.674E-03	9.170E-03	2.080E-02
			12	1.546E-02	1.674E-03	1.298E-02	3.012E-02
			15	1.983E-02	1.674E-03	1.580E-02	3.731E-02
			20	2.756E-02	1.674E-03	2.042E-02	4.966E-02
		90					
			0	0.0	1.674E-03	1.318E-03	2.992E-03
			5	5.287E-03	1.674E-03	7.059E-03	1.402E-02
			8	8.704E-03	1.674E-03	1.044E-02	2.082E-02
			12	1.354E-02	1.674E-03	1.488E-02	3.010E-02
			15	1.739E-02	1.674E-03	1.816E-02	3.723E-02
			20	2.419E-02	1.674E-03	2.355E-02	4.941E-02

DF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P2(7)	2655.8806	50					
			0	0.0	0.0	6.339E-04	6.339E-04
			5	7.617E-03	0.0	2.519E-02	3.281E-02
			8	1.252E-02	0.0	4.036E-02	5.287E-02
			12	1.943E-02	0.0	6.107E-02	8.050E-02
			15	2.490E-02	0.0	7.697E-02	1.019E-01
			20	3.455E-02	0.0	1.041E-01	1.387E-01
		70					
			0	0.0	0.0	7.001E-04	7.001E-04
			5	6.560E-03	0.0	2.585E-02	3.241E-02
			8	1.079E-02	0.0	4.141E-02	5.220E-02
			12	1.677E-02	0.0	6.267E-02	7.944E-02
			15	2.151E-02	0.0	7.900E-02	1.005E-01
			20	2.989E-02	0.0	1.069E-01	1.368E-01
		90					
			0	0.0	0.0	7.663E-04	7.663E-04
			5	5.712E-03	0.0	2.647E-02	3.218E-02
			8	9.404E-03	0.0	4.239E-02	5.179E-02
			12	1.463E-02	0.0	6.416E-02	7.879E-02
			15	1.878E-02	0.0	8.091E-02	9.969E-02
			20	2.614E-02	0.0	1.096E-01	1.357E-01
P1(10)	2665.2183	50					
			0	0.0	0.0	1.873E-03	1.873E-03
			5	7.876E-03	0.0	6.819E-03	1.470E-02
			8	1.294E-02	0.0	9.903E-03	2.284E-02
			12	2.009E-02	0.0	1.415E-02	3.424E-02
			15	2.574E-02	0.0	1.743E-02	4.318E-02
			20	3.573E-02	0.0	2.310E-02	5.882E-02
		70					
			0	0.0	0.0	1.974E-03	1.974E-03
			5	6.773E-03	0.0	7.017E-03	1.379E-02
			8	1.114E-02	0.0	1.017E-02	2.131E-02
			12	1.731E-02	0.0	1.451E-02	3.182E-02
			15	2.221E-02	0.0	1.787E-02	4.007E-02
			20	3.086E-02	0.0	2.367E-02	5.452E-02
		90					
			0	0.0	0.0	2.071E-03	2.071E-03
			5	5.890E-03	0.0	7.203E-03	1.309E-02
			8	9.696E-03	0.0	1.041E-02	2.011E-02
			12	1.509E-02	0.0	1.484E-02	2.993E-02
			15	1.937E-02	0.0	1.827E-02	3.764E-02
			20	2.695E-02	0.0	2.421E-02	5.116E-02

IR ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

IR LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
R2(6)	2680.1731	50					
			0	0.0	0.0	2.900E-04	2.900E-04
			5	8.319E-03	0.0	1.272E-02	2.104E-02
			8	1.367E-02	0.0	2.047E-02	3.413E-02
			12	2.122E-02	0.0	3.111E-02	5.233E-02
			15	2.719E-02	0.0	3.934E-02	6.653E-02
			20	3.773E-02	0.0	5.350E-02	9.123E-02
		70					
			0	0.0	0.0	3.058E-04	3.058E-04
			5	7.137E-03	0.0	1.285E-02	1.998E-02
			8	1.174E-02	0.0	2.067E-02	3.241E-02
			12	1.824E-02	0.0	3.144E-02	4.968E-02
			15	2.340E-02	0.0	3.977E-02	6.317E-02
			20	3.252E-02	0.0	5.412E-02	8.664E-02
		90					
			0	0.0	0.0	3.205E-04	3.205E-04
			5	6.192E-03	0.0	1.297E-02	1.916E-02
			8	1.019E-02	0.0	2.086E-02	3.106E-02
			12	1.586E-02	0.0	3.175E-02	4.761E-02
			15	2.036E-02	0.0	4.018E-02	6.054E-02
			20	2.834E-02	0.0	5.473E-02	8.306E-02
P1(9)	2691.6050	50					
			0	0.0	0.0	7.928E-03	7.928E-03
			5	8.682E-03	0.0	1.273E-02	2.141E-02
			8	1.427E-02	0.0	1.574E-02	3.001E-02
			12	2.214E-02	0.0	1.992E-02	4.207E-02
			15	2.838E-02	0.0	2.318E-02	5.155E-02
			20	3.938E-02	0.0	2.882E-02	6.820E-02
		70					
			0	0.0	0.0	8.433E-03	8.433E-03
			5	7.435E-03	0.0	1.326E-02	2.070E-02
			8	1.223E-02	0.0	1.630E-02	2.853E-02
			12	1.900E-02	0.0	2.052E-02	3.953E-02
			15	2.437E-02	0.0	2.381E-02	4.818E-02
			20	3.387E-02	0.0	2.951E-02	6.339E-02
		90					
			0	0.0	0.0	8.916E-03	8.916E-03
			5	6.440E-03	0.0	1.380E-02	2.024E-02
			8	1.060E-02	0.0	1.687E-02	2.747E-02
			12	1.650E-02	0.0	2.114E-02	3.764E-02
			15	2.118E-02	0.0	2.447E-02	4.565E-02
			20	2.947E-02	0.0	3.025E-02	5.972E-02

DF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1) .
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P2(5)	2703.9983	50					
			0	0.0	0.0	1.760E-06	1.760E-06
			5	9.127E-03	0.0	1.724E-03	1.085E-02
			8	1.500E-02	0.0	2.795E-03	1.779E-02
			12	2.328E-02	0.0	4.265E-03	2.754E-02
			15	2.983E-02	0.0	5.399E-03	3.523E-02
			20	4.140E-02	0.0	7.349E-03	4.875E-02
		70					
			0	0.0	0.0	1.801E-06	1.801E-06
			5	7.801E-03	0.0	1.880E-03	9.681E-03
			8	1.283E-02	0.0	3.048E-03	1.588E-02
			12	1.994E-02	0.0	4.654E-03	2.459E-02
			15	2.558E-02	0.0	5.894E-03	3.147E-02
			20	3.554E-02	0.0	8.028E-03	4.357E-02
		90					
			0	0.0	0.0	1.836E-06	1.836E-06
			5	6.745E-03	0.0	2.064E-03	8.809E-03
			8	1.110E-02	0.0	3.349E-03	1.445E-02
			12	1.728E-02	0.0	5.116E-03	2.239E-02
			15	2.218E-02	0.0	6.482E-03	2.866E-02
			20	3.086E-02	0.0	8.834E-03	3.970E-02
P1(3)	2717.5427	50					
			0	0.0	0.0	2.097E-06	2.097E-06
			5	9.691E-03	0.0	3.652E-02	4.621E-02
			8	1.592E-02	0.0	5.902E-02	7.495E-02
			12	2.472E-02	0.0	8.969E-02	1.144E-01
			15	3.167E-02	0.0	1.132E-01	1.449E-01
			20	4.396E-02	0.0	1.532E-01	1.972E-01
		70					
			0	0.0	0.0	2.110E-06	2.110E-06
			5	8.265E-03	0.0	3.952E-02	4.779E-02
			8	1.359E-02	0.0	6.391E-02	7.750E-02
			12	2.113E-02	0.0	9.719E-02	1.183E-01
			15	2.710E-02	0.0	1.227E-01	1.498E-01
			20	3.765E-02	0.0	1.663E-01	2.040E-01
		90					
			0	0.0	0.0	2.117E-06	2.117E-06
			5	7.132E-03	0.0	4.254E-02	4.967E-02
			8	1.174E-02	0.0	6.883E-02	8.058E-02
			12	1.827E-02	0.0	1.048E-01	1.230E-01
			15	2.345E-02	0.0	1.324E-01	1.558E-01
			20	3.263E-02	0.0	1.795E-01	2.122E-01

DF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P2(4)	2727.3115	50					
			0	0.0	0.0	1.601E-04	1.601E-04
			5	1.010E-02	0.0	9.662E-03	1.976E-02
			8	1.659E-02	0.0	1.552E-02	3.211E-02
			12	2.576E-02	0.0	2.349E-02	4.925E-02
			15	3.301E-02	0.0	2.960E-02	6.261E-02
			20	4.581E-02	0.0	4.002E-02	8.583E-02
		70					
			0	0.0	0.0	1.614E-04	1.614E-04
			5	8.600E-03	0.0	1.037E-02	1.897E-02
			8	1.414E-02	0.0	1.666E-02	3.081E-02
			12	2.198E-02	0.0	2.523E-02	4.721E-02
			15	2.819E-02	0.0	3.179E-02	5.998E-02
			20	3.918E-02	0.0	4.296E-02	8.214E-02
		90					
			0	0.0	0.0	1.626E-04	1.626E-04
			5	7.410E-03	0.0	1.113E-02	1.854E-02
			8	1.220E-02	0.0	1.788E-02	3.008E-02
			12	1.898E-02	0.0	2.707E-02	4.605E-02
			15	2.437E-02	0.0	3.410E-02	5.846E-02
			20	3.391E-02	0.0	4.607E-02	7.997E-02
P1(7)	2742.9875	50					
			0	0.0	0.0	2.059E-03	2.059E-03
			5	1.068E-02	0.0	3.939E-03	1.462E-02
			8	1.754E-02	0.0	5.068E-03	2.261E-02
			12	2.723E-02	0.0	6.572E-03	3.380E-02
			15	3.489E-02	0.0	7.700E-03	4.259E-02
			20	4.841E-02	0.0	9.581E-03	5.799E-02
		70					
			0	0.0	0.0	1.888E-03	1.888E-03
			5	9.072E-03	0.0	3.795E-03	1.287E-02
			8	1.492E-02	0.0	4.939E-03	1.986E-02
			12	2.318E-02	0.0	6.464E-03	2.964E-02
			15	2.972E-02	0.0	7.608E-03	3.733E-02
			20	4.130E-02	0.0	9.515E-03	5.081E-02
		90					
			0	0.0	0.0	1.735E-03	1.735E-03
			5	7.799E-03	0.0	3.575E-03	1.137E-02
			8	1.284E-02	0.0	4.679E-03	1.751E-02
			12	1.997E-02	0.0	6.151E-03	2.612E-02
			15	2.563E-02	0.0	6.974E-03	3.260E-02
			20	3.566E-02	0.0	8.721E-03	4.438E-02

OF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

OF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P2(3)	2750.0962	50					
			0	0.0	0.0	1.061E-03	1.061E-03
			5	1.106E-02	0.0	5.140E-03	1.620E-02
			8	1.817E-02	0.0	7.673E-03	2.584E-02
			12	2.820E-02	0.0	1.115E-02	3.935E-02
			15	3.614E-02	0.0	1.383E-02	4.997E-02
			20	5.015E-02	0.0	1.843E-02	6.858E-02
		70					
			0	0.0	0.0	1.053E-03	1.053E-03
			5	9.382E-03	0.0	5.140E-03	1.452E-02
			8	1.543E-02	0.0	7.682E-03	2.311E-02
			12	2.398E-02	0.0	1.117E-02	3.515E-02
			15	3.076E-02	0.0	1.387E-02	4.462E-02
			20	4.274E-02	0.0	1.850E-02	6.124E-02
		90					
			0	0.0	0.0	1.044E-03	1.044E-03
			5	8.057E-03	0.0	5.140E-03	1.320E-02
			8	1.326E-02	0.0	7.691E-03	2.095E-02
			12	2.064E-02	0.0	1.120E-02	3.184E-02
			15	2.649E-02	0.0	1.391E-02	4.040E-02
			20	3.687E-02	0.0	1.857E-02	5.543E-02
P1(6)	2767.9685	50					
			0	0.0	0.0	5.089E-03	5.089E-03
			5	1.181E-02	0.0	2.228E-02	3.410E-02
			8	1.941E-02	0.0	3.299E-02	5.240E-02
			12	3.013E-02	0.0	4.771E-02	7.785E-02
			15	3.861E-02	0.0	5.909E-02	9.770E-02
			20	5.359E-02	0.0	7.868E-02	1.323E-01
		70					
			0	0.0	0.0	5.079E-03	5.079E-03
			5	9.995E-03	0.0	2.226E-02	3.226E-02
			8	1.644E-02	0.0	3.298E-02	4.942E-02
			12	2.555E-02	0.0	4.774E-02	7.328E-02
			15	3.277E-02	0.0	5.915E-02	9.192E-02
			20	4.554E-02	0.0	7.882E-02	1.244E-01
		90					
			0	0.0	0.0	5.063E-03	5.063E-03
			5	8.561E-03	0.0	2.224E-02	3.080E-02
			8	1.409E-02	0.0	3.297E-02	4.706E-02
			12	2.193E-02	0.0	4.775E-02	6.968E-02
			15	2.815E-02	0.0	5.920E-02	8.735E-02
			20	3.917E-02	0.0	7.895E-02	1.181E-01

DF ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

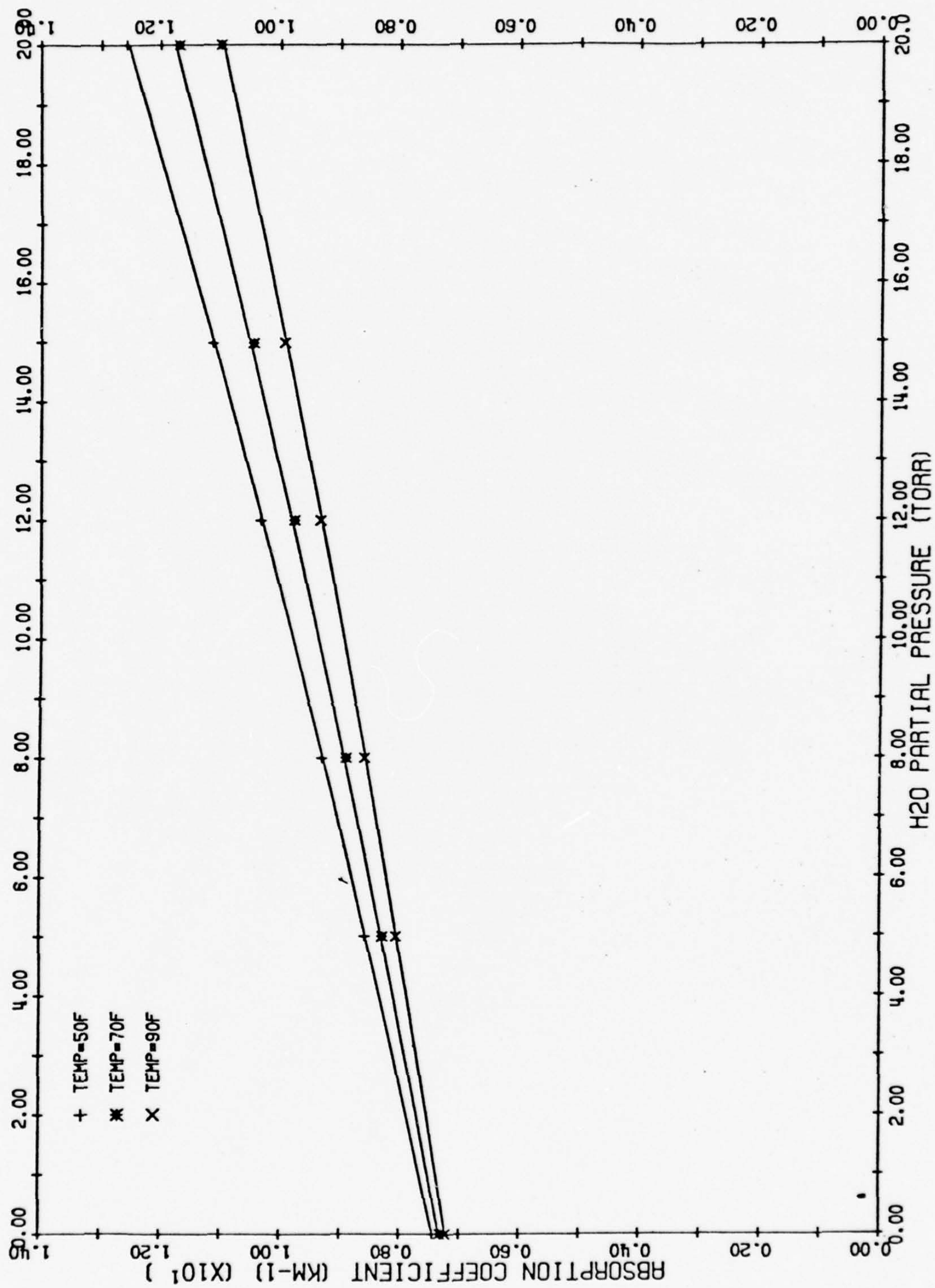
DF LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P3(8)	2546.3745	50					
			0	0.0	8.393E-03	2.317E-02	3.156E-02
			5	7.026E-03	8.393E-03	2.350E-02	3.892E-02
			8	1.154E-02	8.393E-03	2.370E-02	4.364E-02
			12	1.792E-02	8.393E-03	2.399E-02	5.030E-02
			15	2.296E-02	8.393E-03	2.421E-02	5.550E-02
			20	3.187E-02	8.393E-03	2.458E-02	6.485E-02
		70					
			0	0.0	8.292E-03	2.265E-02	3.094E-02
			5	6.053E-03	8.292E-03	2.304E-02	3.738E-02
			8	9.955E-03	8.292E-03	2.328E-02	4.153E-02
			12	1.547E-02	8.292E-03	2.362E-02	4.738E-02
			15	1.984E-02	8.292E-03	2.368E-02	5.202E-02
			20	2.758E-02	8.292E-03	2.433E-02	6.020E-02
		90					
			0	0.0	8.198E-03	2.212E-02	3.032E-02
			5	5.272E-03	8.198E-03	2.258E-02	3.605E-02
			8	8.680E-03	8.198E-03	2.286E-02	3.974E-02
			12	1.351E-02	8.198E-03	2.326E-02	4.497E-02
			15	1.734E-02	8.198E-03	2.357E-02	4.911E-02
			20	2.413E-02	8.198E-03	2.410E-02	5.643E-02
P2(11)	2553.9539	50					
			0	0.0	7.168E-03	1.104E-02	1.821E-02
			5	6.848E-03	7.168E-03	1.118E-02	2.520E-02
			8	1.125E-02	7.168E-03	1.127E-02	2.969E-02
			12	1.747E-02	7.168E-03	1.140E-02	3.603E-02
			15	2.238E-02	7.168E-03	1.149E-02	4.104E-02
			20	3.106E-02	7.168E-03	1.166E-02	4.989E-02
		70					
			0	0.0	7.093E-03	1.058E-02	1.767E-02
			5	5.907E-03	7.093E-03	1.075E-02	2.375E-02
			8	9.716E-03	7.093E-03	1.086E-02	2.767E-02
			12	1.510E-02	7.093E-03	1.100E-02	3.320E-02
			15	1.937E-02	7.093E-03	1.112E-02	3.758E-02
			20	2.691E-02	7.093E-03	1.132E-02	4.532E-02
		90					
			0	0.0	7.025E-03	1.015E-02	1.718E-02
			5	5.151E-03	7.025E-03	1.036E-02	2.253E-02
			8	8.481E-03	7.025E-03	1.048E-02	2.599E-02
			12	1.320E-02	7.025E-03	1.066E-02	3.088E-02
			15	1.694E-02	7.025E-03	1.079E-02	3.476E-02
			20	2.357E-02	7.025E-03	1.103E-02	4.162E-02

IR ATMOSPHERIC ABSORPTION COEFFICIENTS (KM-1)
AS A FUNCTION OF TEMPERATURE & WATER VAPOR PARTIAL PRESSURE

IR LINE	FREQUENCY (CM-1)	TEMP (F)	PRESS (TORR)	H2O CONTINUUM	N2 CONTINUUM	LINE TOTAL	TOTAL
P1(3)	2839.7954	50					
			0	0.0	0.0	6.525E-04	6.525E-04
			5	1.490E-02	0.0	9.613E-03	2.452E-02
			8	2.449E-02	0.0	1.495E-02	3.944E-02
			12	3.801E-02	0.0	2.204E-02	6.006E-02
			15	4.871E-02	0.0	2.733E-02	7.605E-02
			20	6.761E-02	0.0	3.612E-02	1.037E-01
		70					
			0	0.0	0.0	8.363E-04	8.363E-04
			5	1.247E-02	0.0	1.042E-02	2.289E-02
			8	2.050E-02	0.0	1.614E-02	3.664E-02
			12	3.187E-02	0.0	2.372E-02	5.559E-02
			15	4.087E-02	0.0	2.938E-02	7.026E-02
			20	5.680E-02	0.0	3.879E-02	9.559E-02
		90					
			0	0.0	0.0	1.050E-03	1.050E-03
			5	1.057E-02	0.0	1.130E-02	2.187E-02
			8	1.739E-02	0.0	1.741E-02	3.481E-02
			12	2.707E-02	0.0	2.552E-02	5.259E-02
			15	3.475E-02	0.0	3.158E-02	6.632E-02
			20	4.835E-02	0.0	4.163E-02	8.998E-02

APPENDIX B

ANALYTIC CURVE FITS TO CALCULATED DF LASER ABSORPTION



ABSORPTION COEFICIENTS FOR THE P3(12) OF LINE
AT 2445.354 WAVENUMBERS

Figure 1.

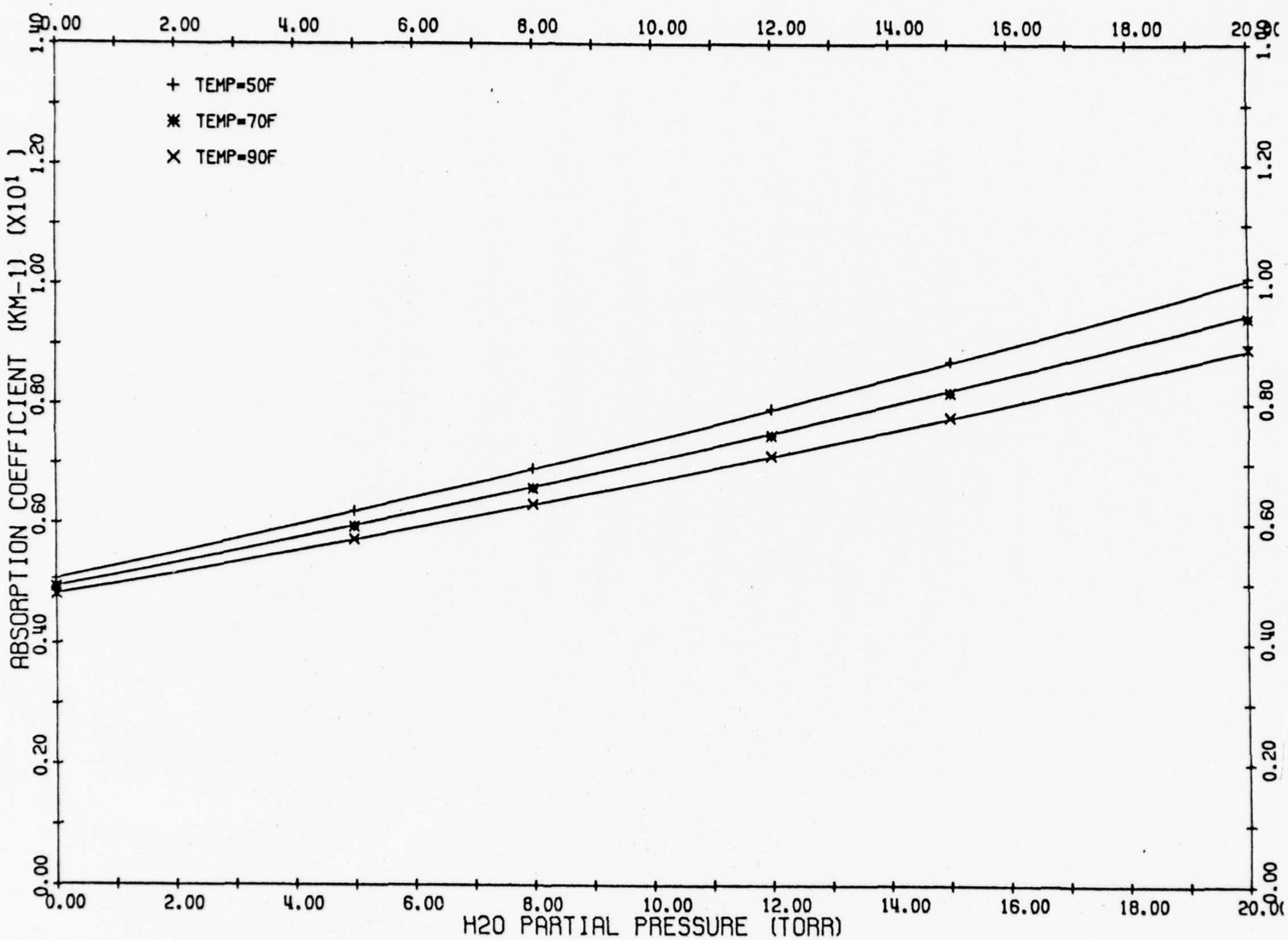


Figure 2. ABSORPTION COEFICIENTS FOR THE P3(11) DF LINE AT 2471.245 WAVENUMBERS

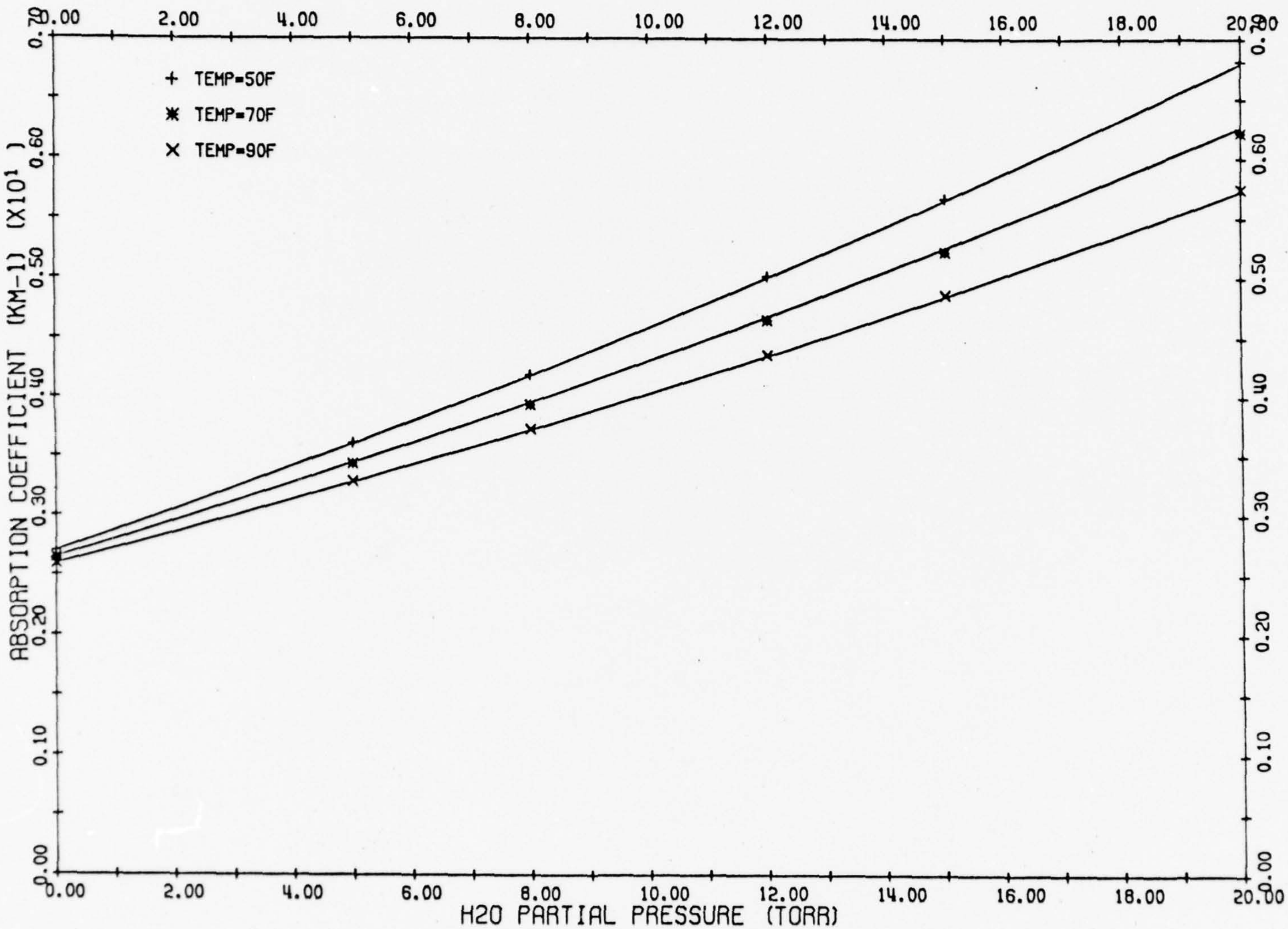


Figure 3. ABSORPTION COEFICIENTS FOR THE P3(10) DF LINE AT 2496.722 WAVENUMBERS

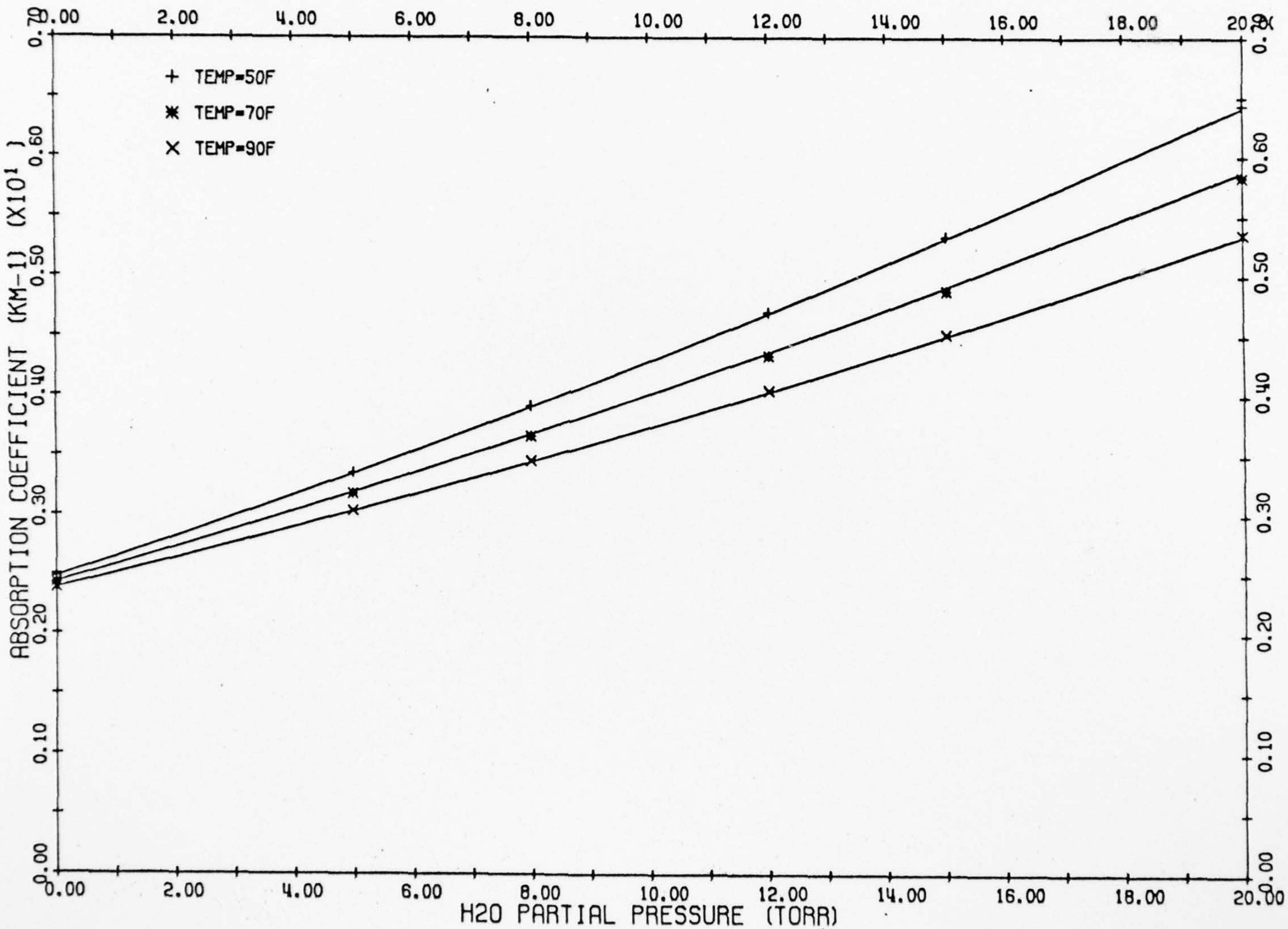


Figure 4. ABSORPTION COEFICIENTS FOR THE P2(13) DF LINE AT 2500.430 WAVENUMBERS

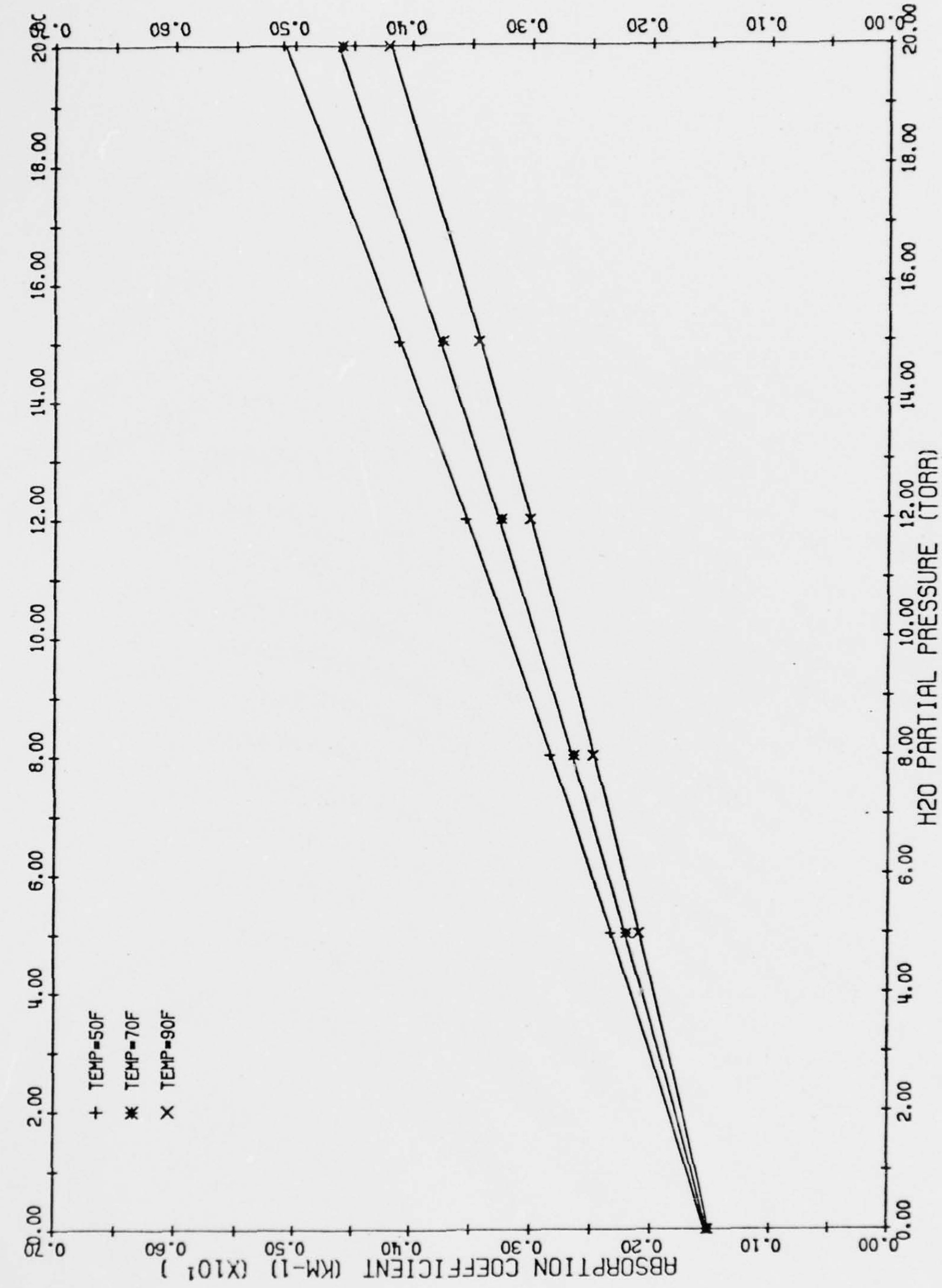


Figure 5. ABSORPTION COEFICIENTS FOR THE P3(9) OF LINE AT 2521.769 WAVENUMBERS

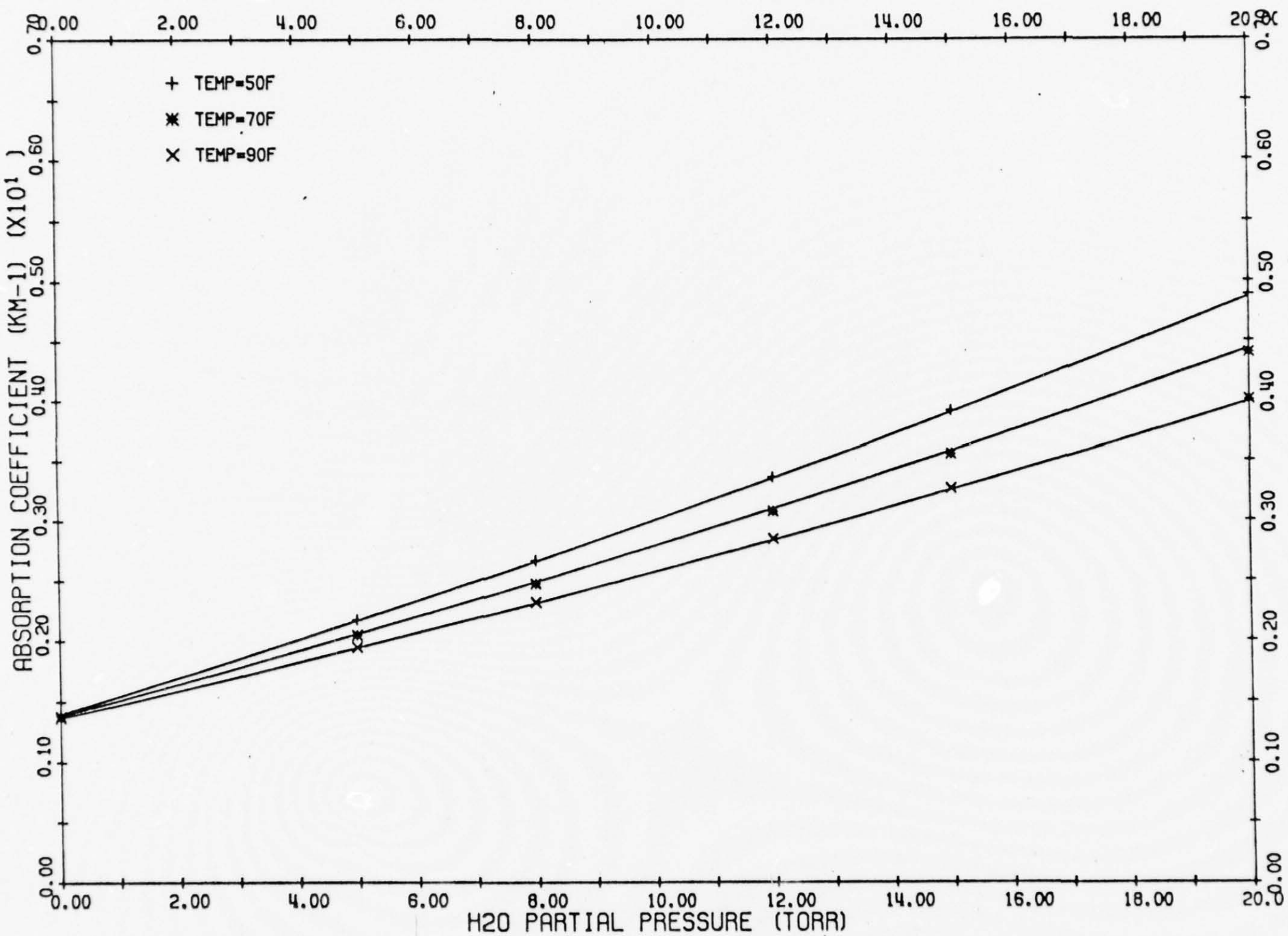


Figure 6. ABSORPTION COEFICIENTS FOR THE P2(12) OF LINE AT 2527.387 WAVENUMBERS

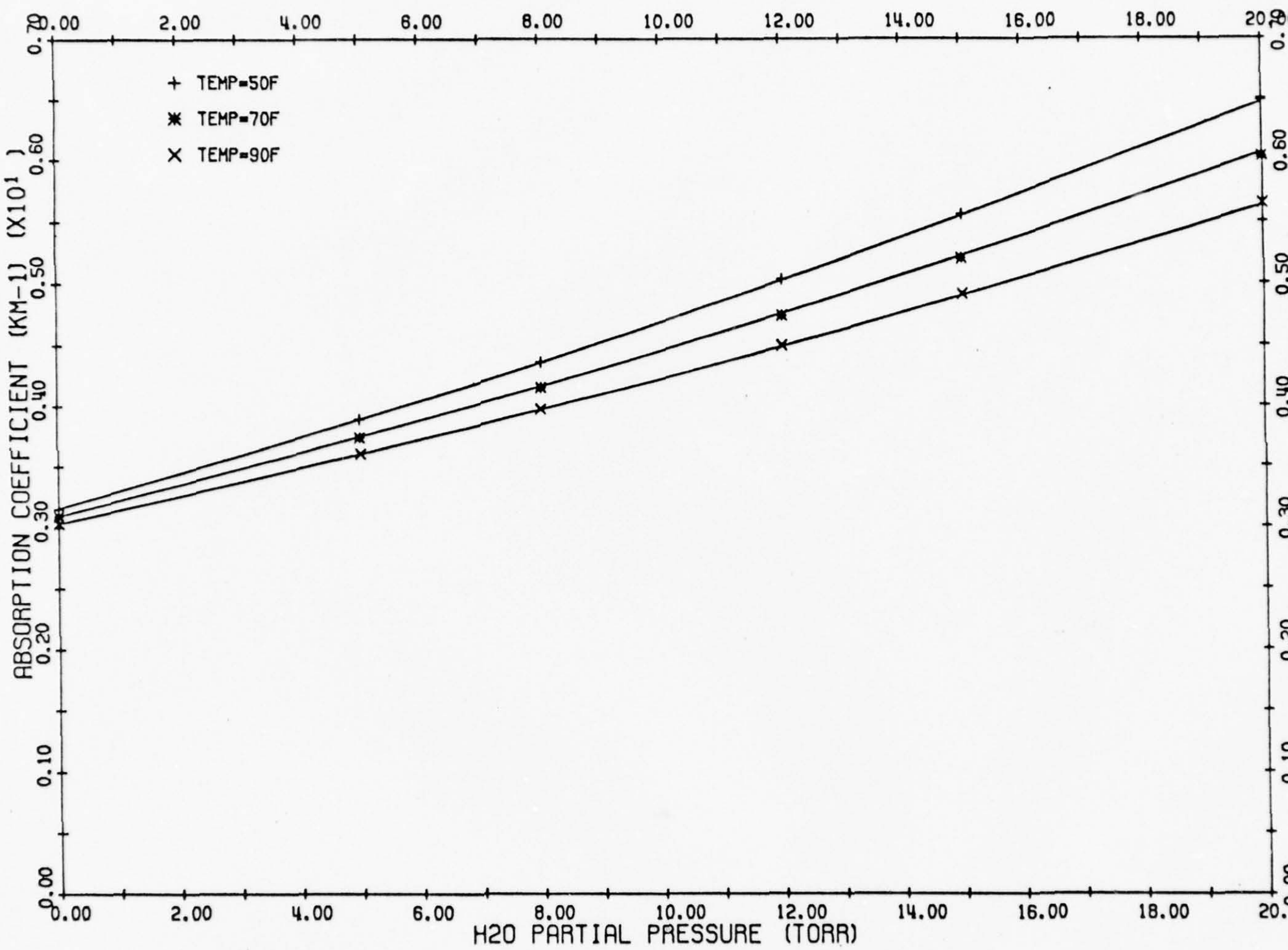


Figure 7. ABSORPTION COEFICIENTS FOR THE P3(8) DF LINE AT 2546.375 WAVENUMBERS

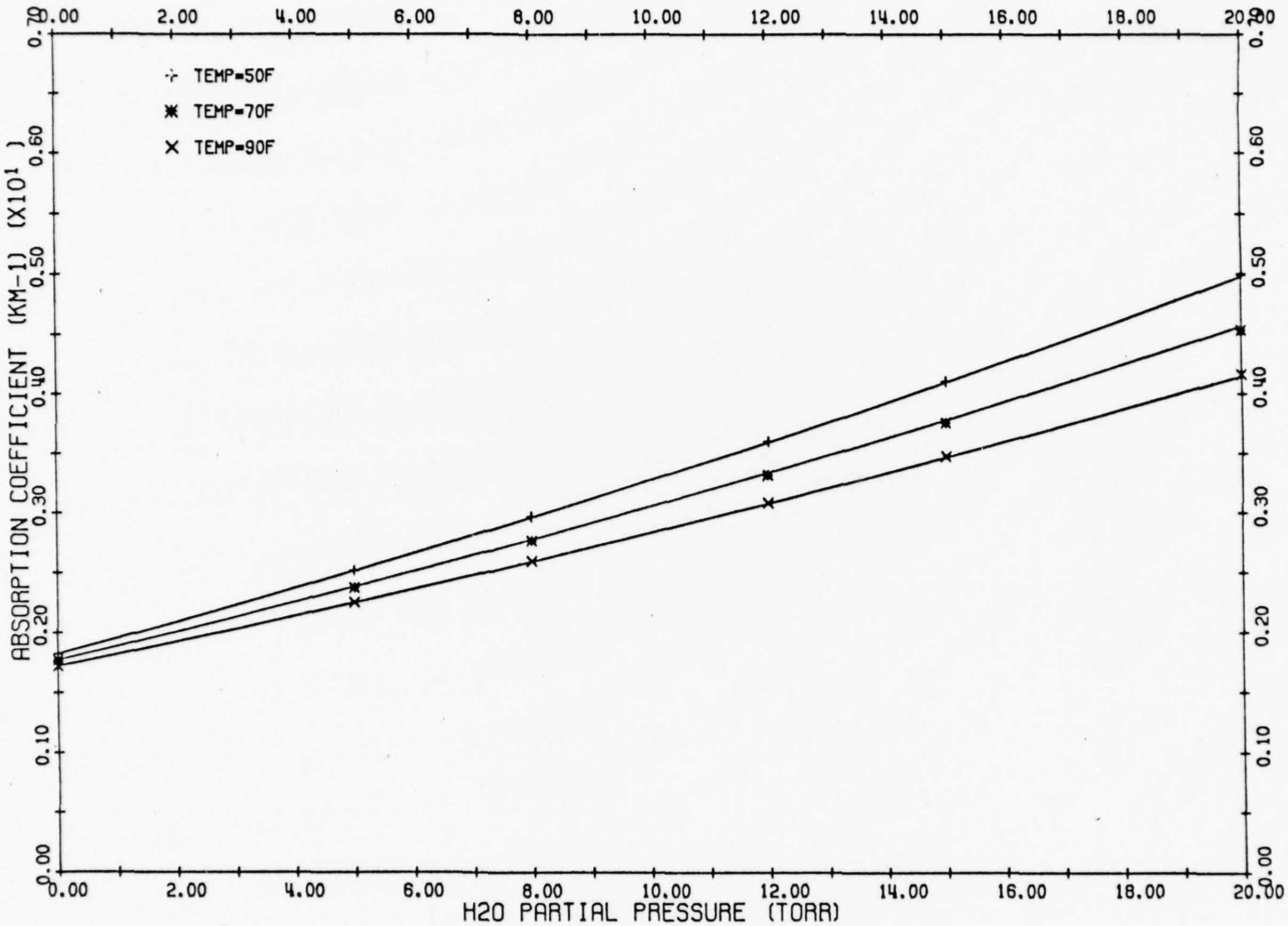


Figure 8. ABSORPTION COEFICIENTS FOR THE P2(11) OF LINE AT 2553.954 WAVENUMBERS

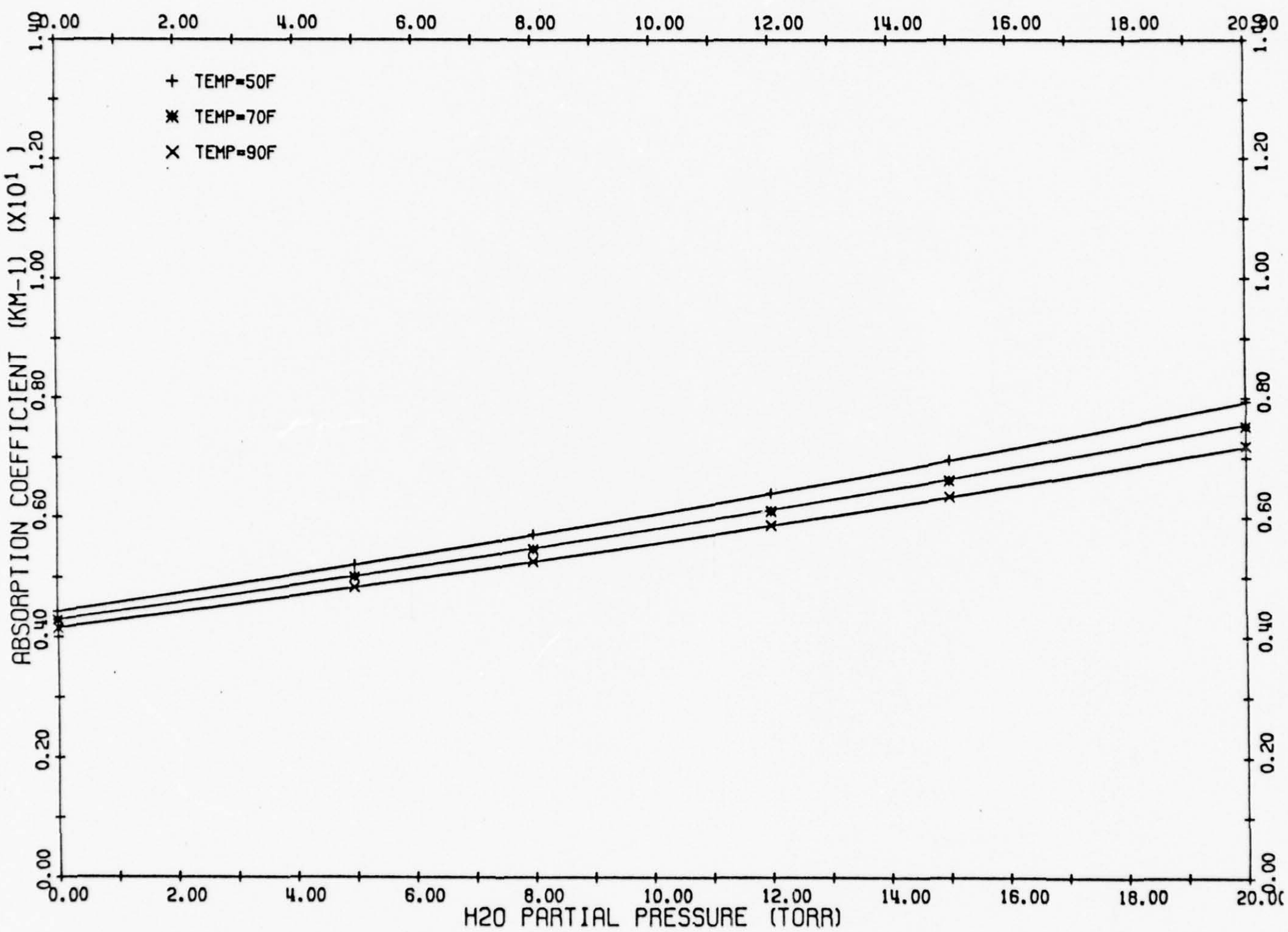


Figure 9. ABSORPTION COEFICIENTS FOR THE P3(7) DF LINE AT 2570.523 WAVENUMBERS

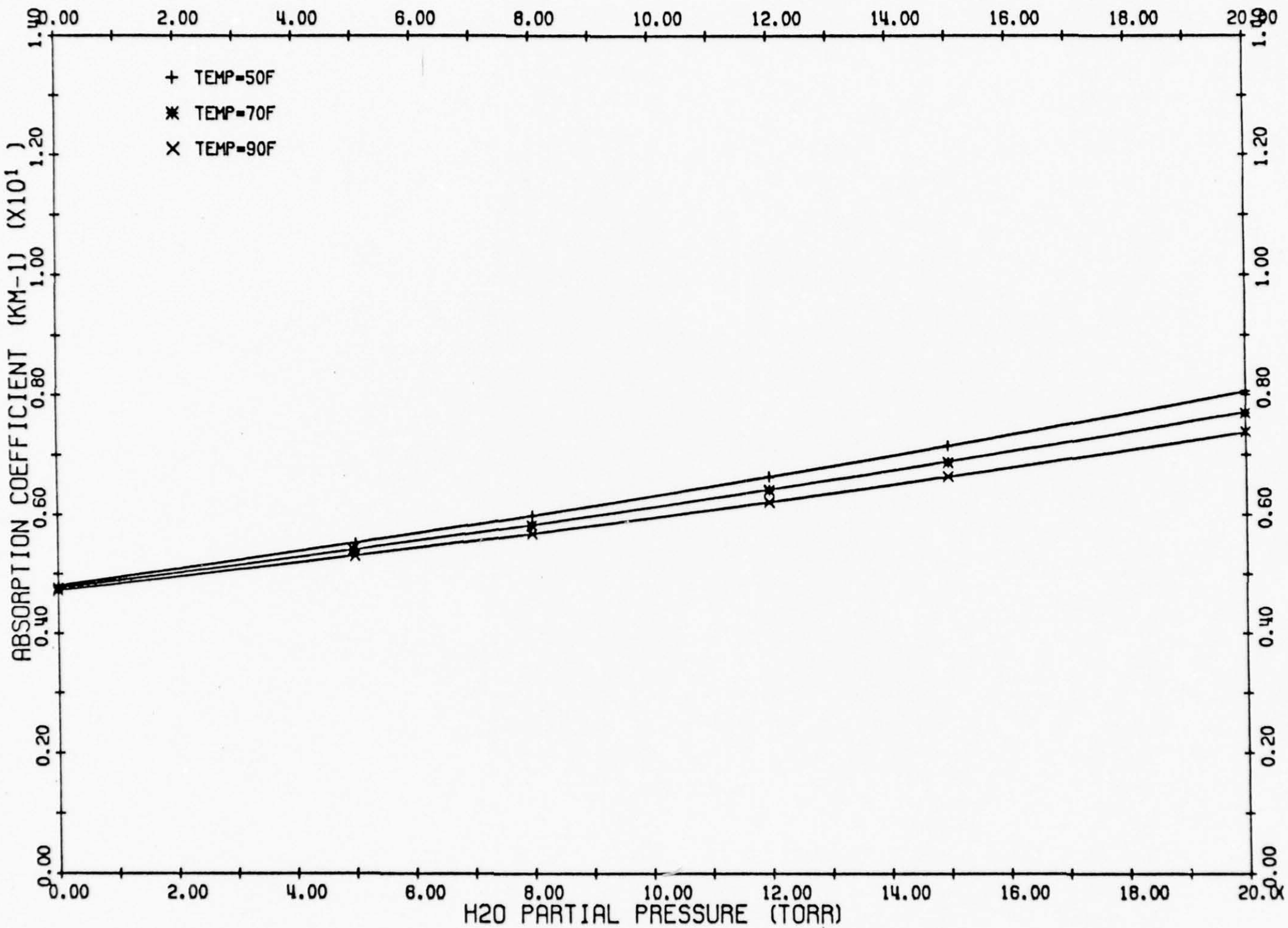


Figure 10. ABSORPTION COEFICIENTS FOR THE P2(10) OF LINE
AT 2580.102 WAVENUMBERS

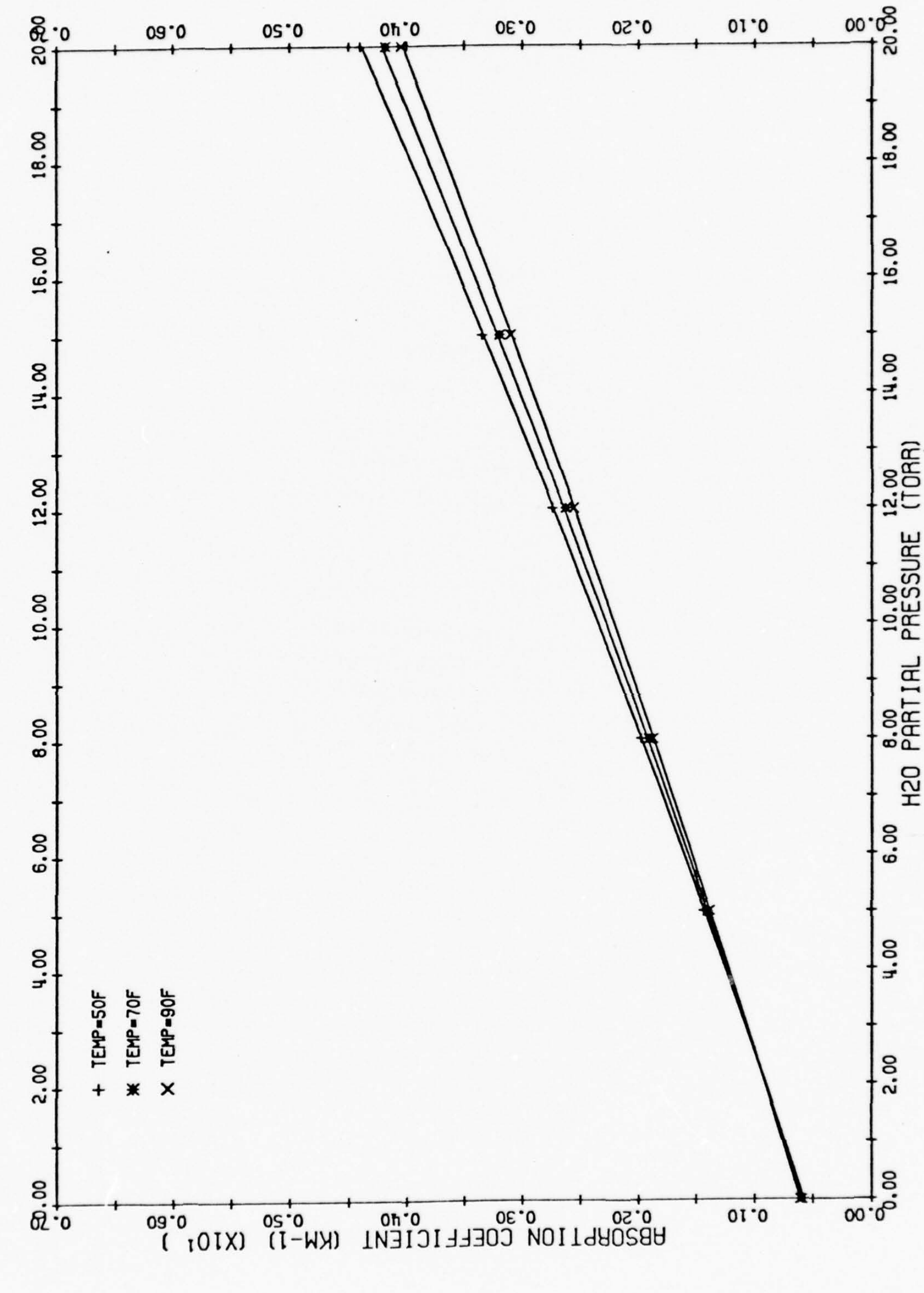


Figure 11. ABSORPTION COEFICIENTS FOR THE P3(6) DF LINE AT 2594.201 WAVENUMBERS

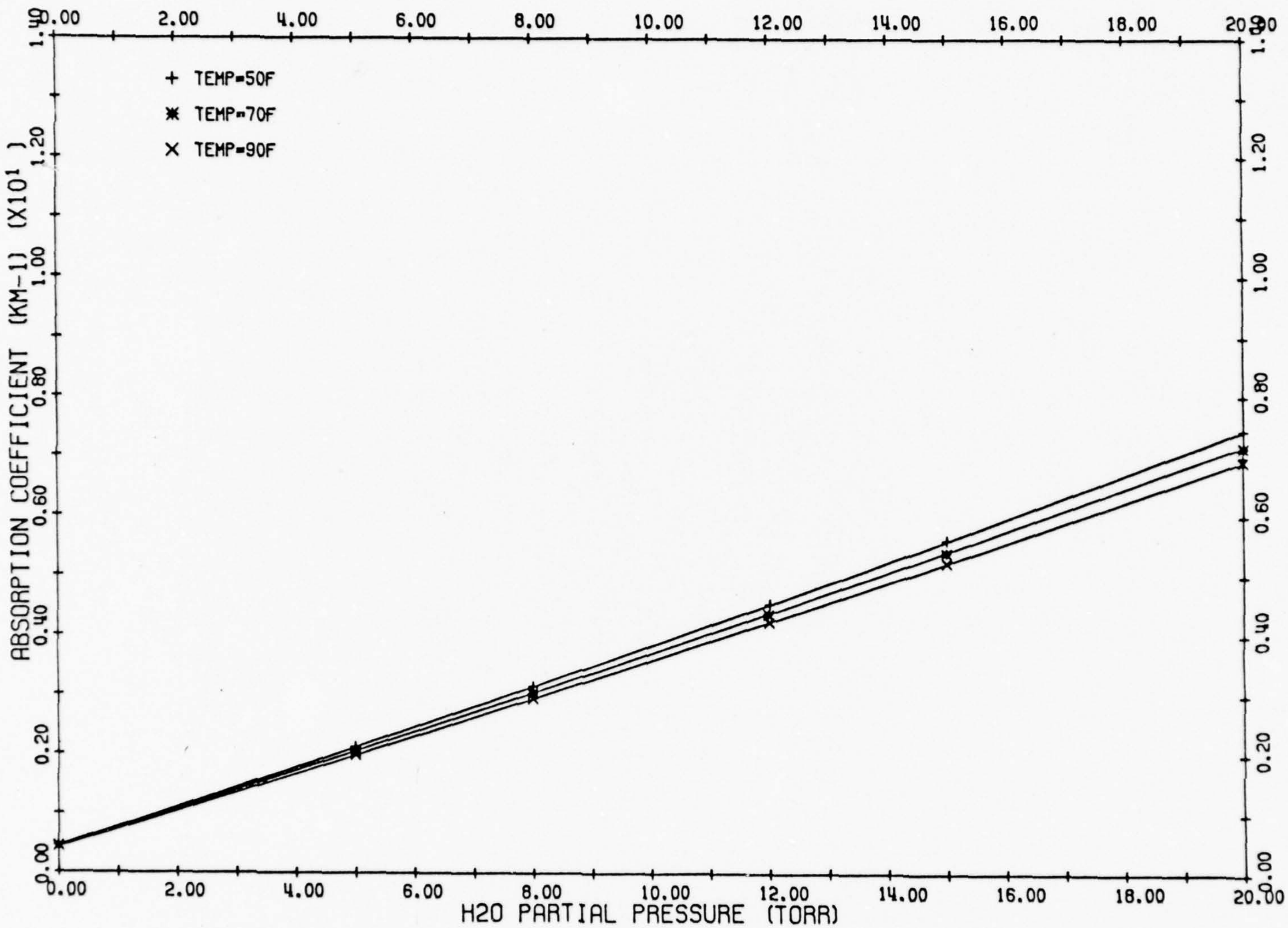


Figure 12. ABSORPTION COEFICIENTS FOR THE P2(9) OF LINE AT 2605.808 WAVENUMBERS

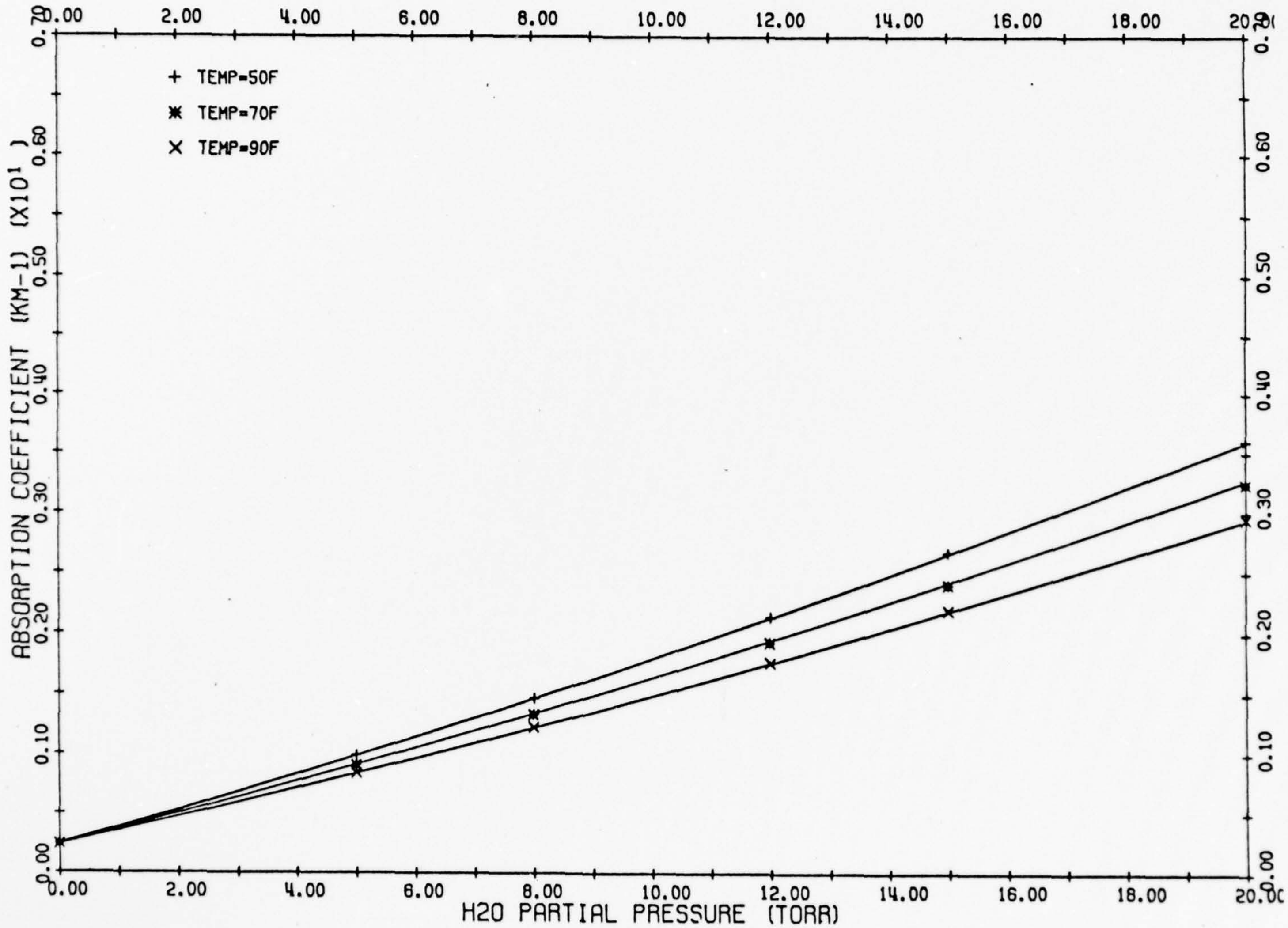


Figure 13. ABSORPTION COEFICIENTS FOR THE P3(5) DF LINE AT 2617.389 WAVENUMBERS

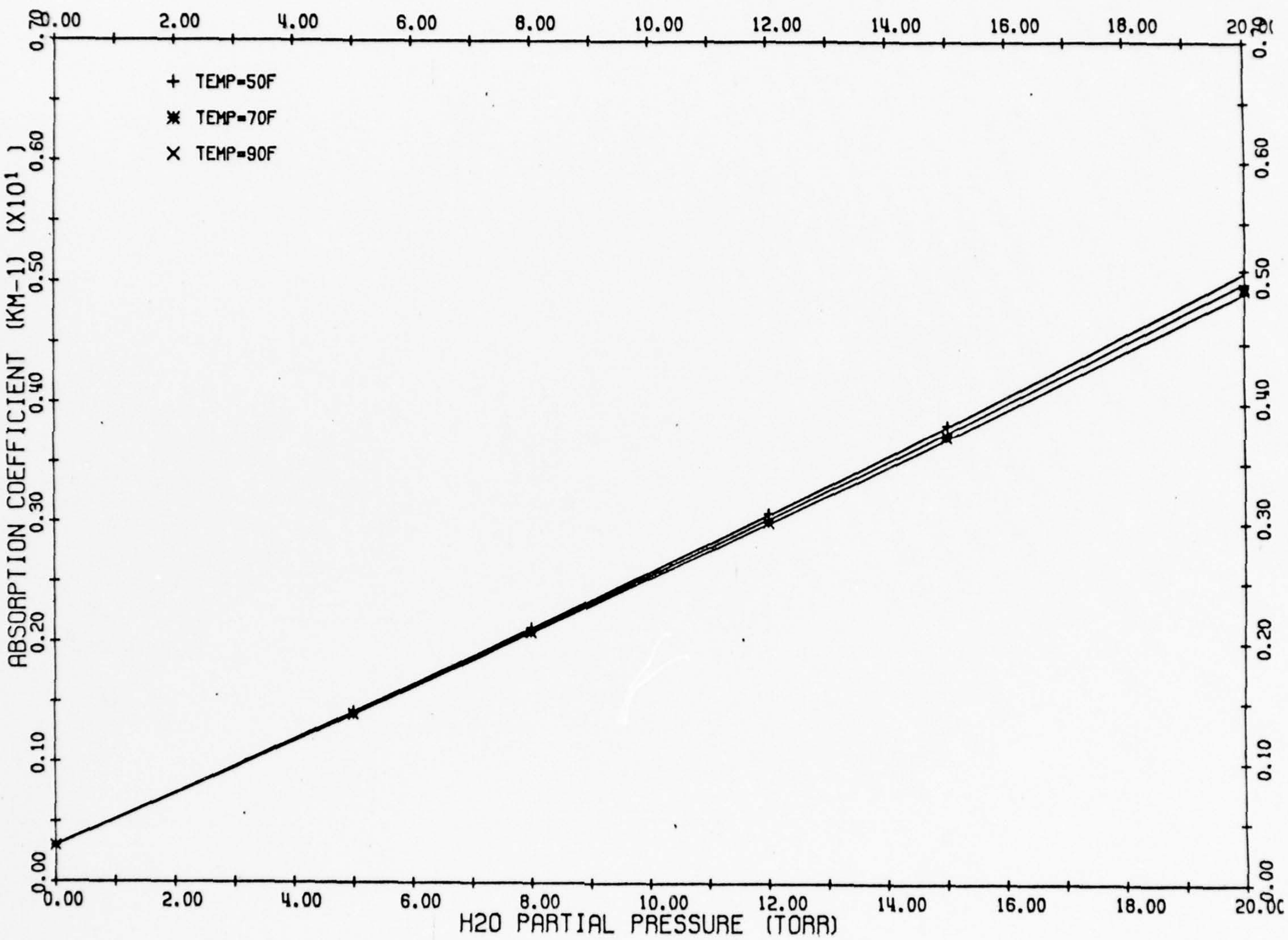


Figure 14. ABSORPTION COEFICIENTS FOR THE P2(8) OF LINE AT 2631.067 WAVENUMBERS

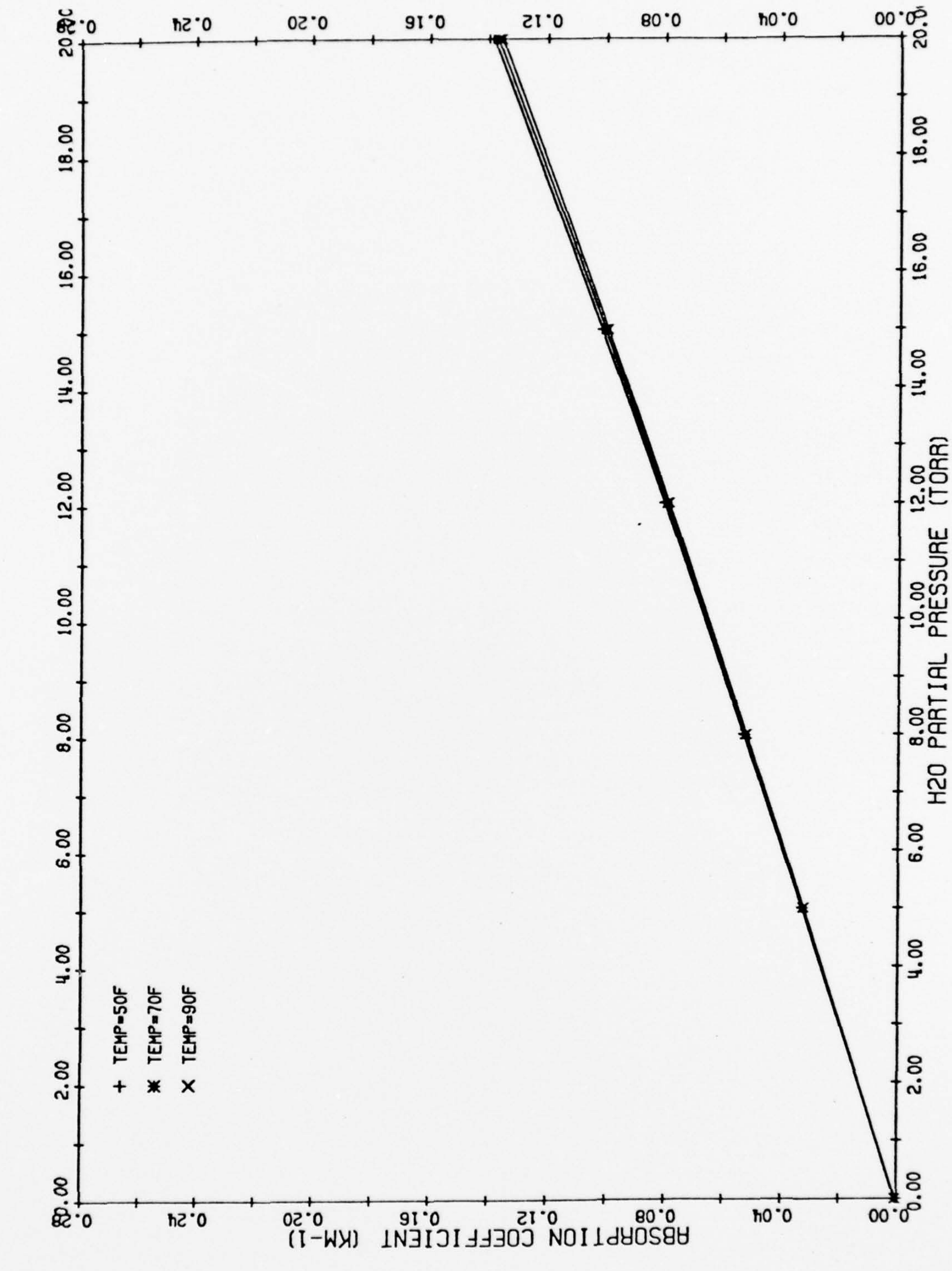


Figure 15. ABSORPTION COEFICIENTS FOR THE P2(7) OF LINE AT 2655.861 WAVENUMBERS

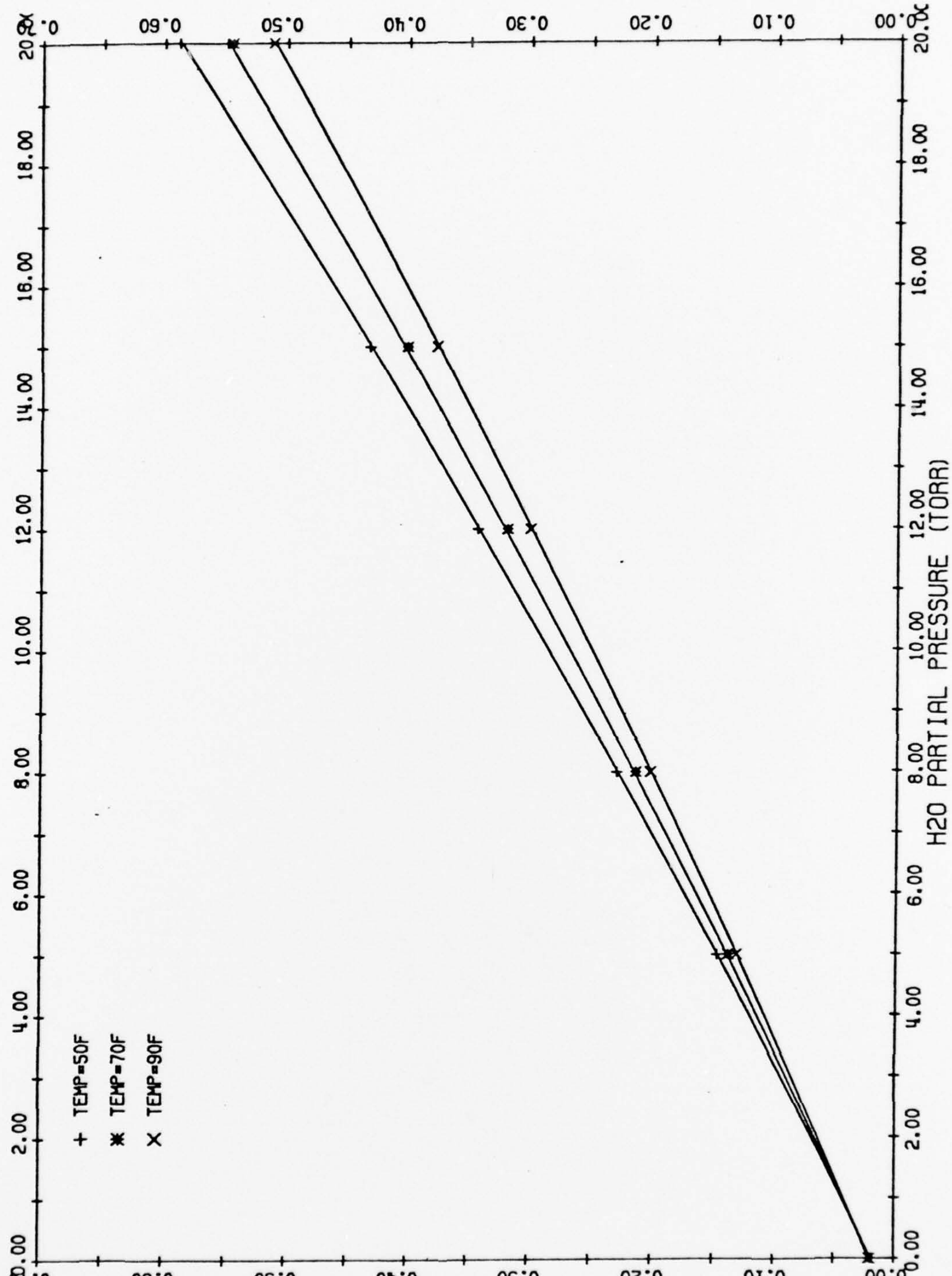


Figure 16. ABSORPTION COEFICIENTS FOR THE P1(10) OF LINE AT 2665.218 WAVENUMBERS

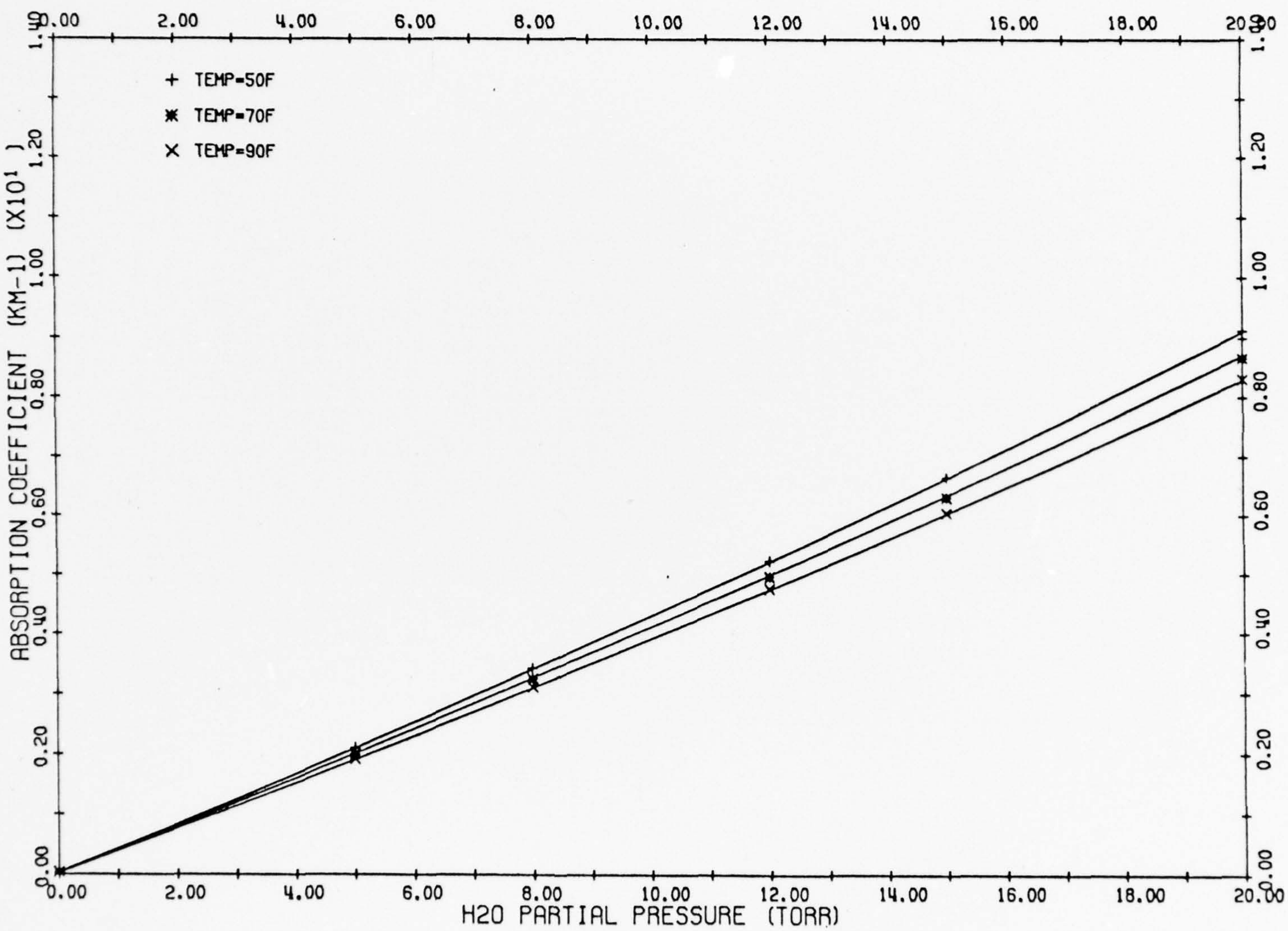


Figure 17. ABSORPTION COEFICIENTS FOR THE P2(6) DF LINE AT 2680.173 WAVENUMBERS

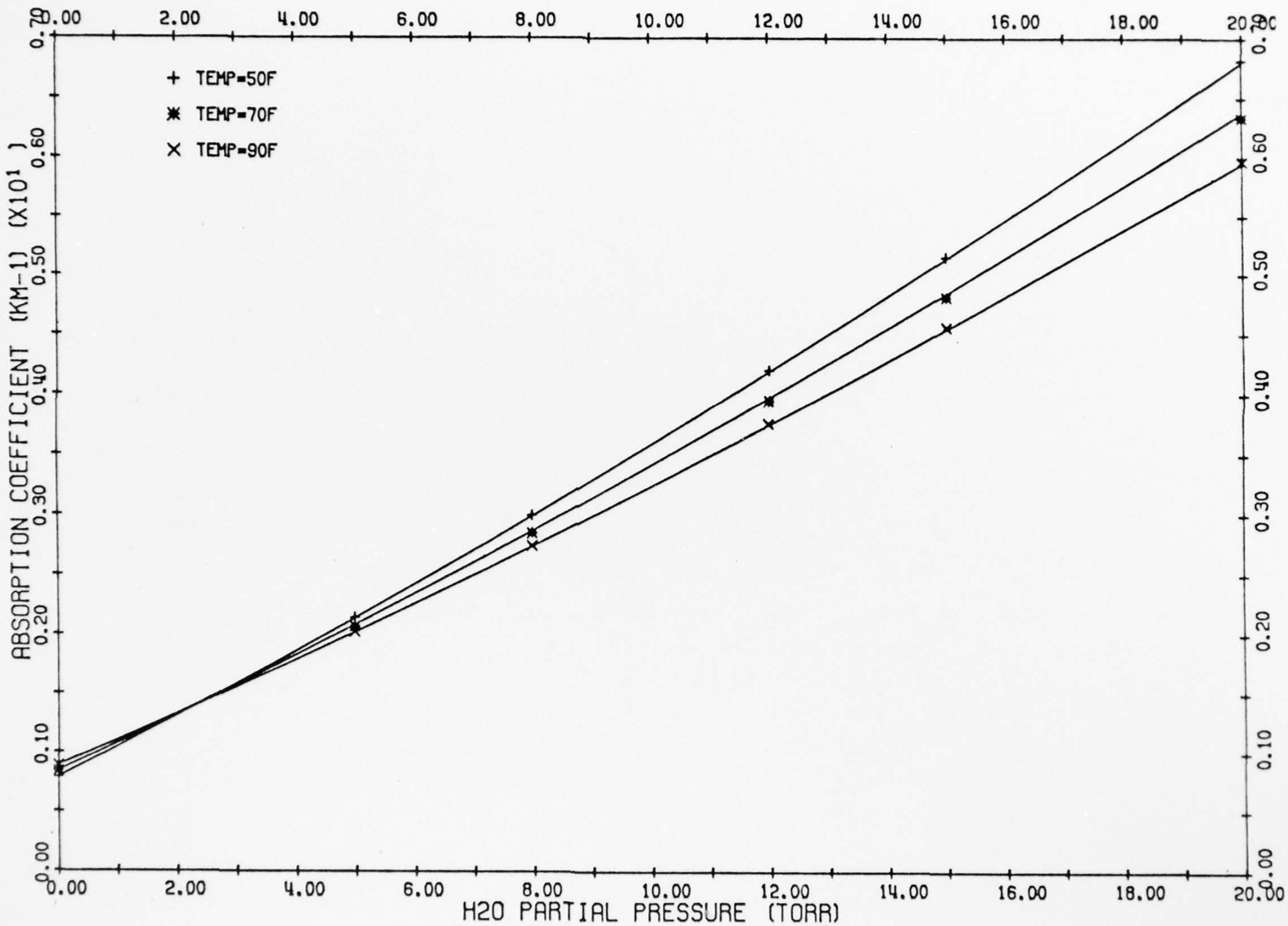


Figure 18. ABSORPTION COEFICIENTS FOR THE P1 (9) DF LINE AT 2691.605 WAVENUMBERS

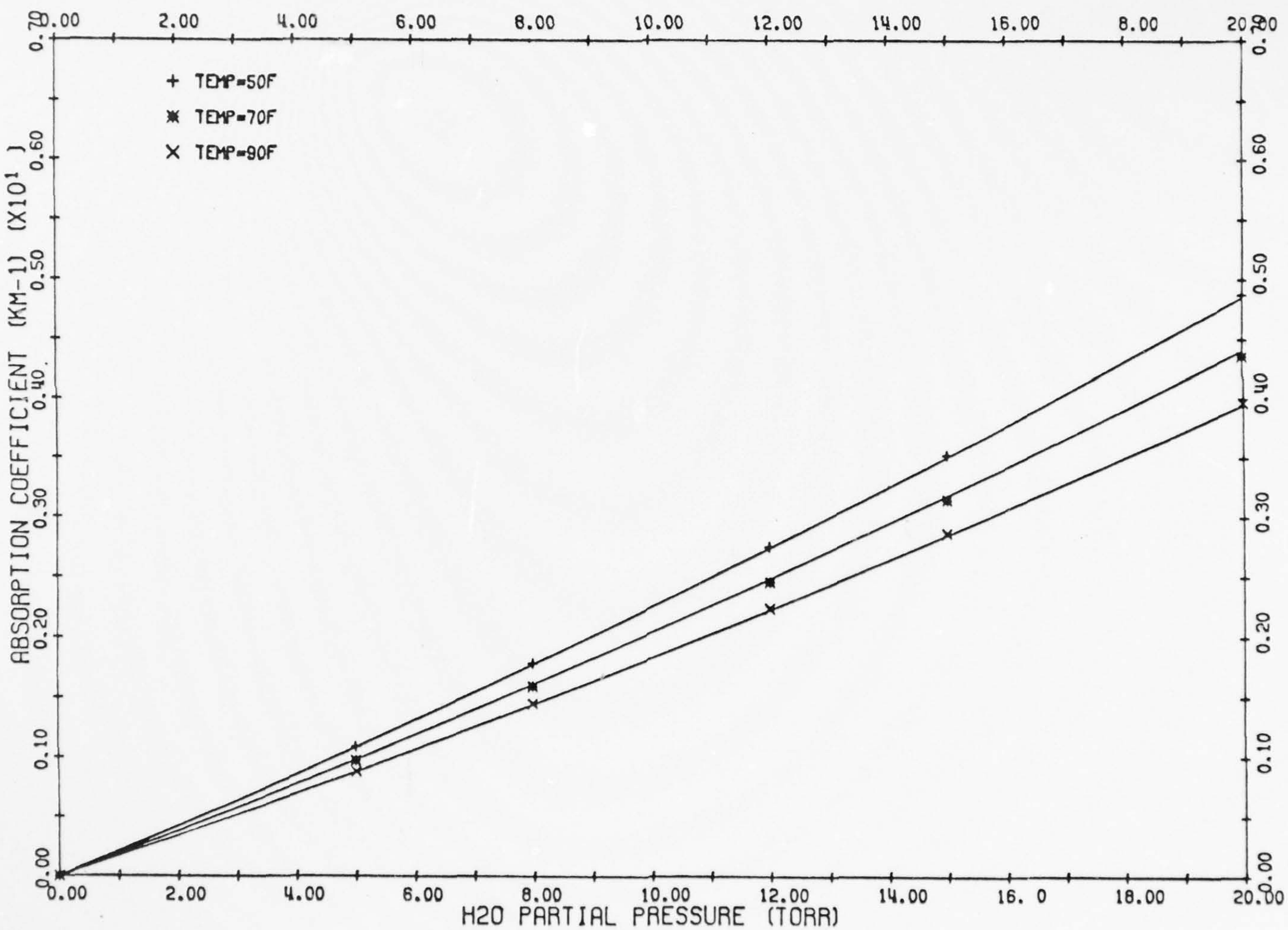


Figure 19. ABSORPTION COEFICIENTS FOR THE P2(5) OF LINE AT 2703.998 WAVENUMBERS

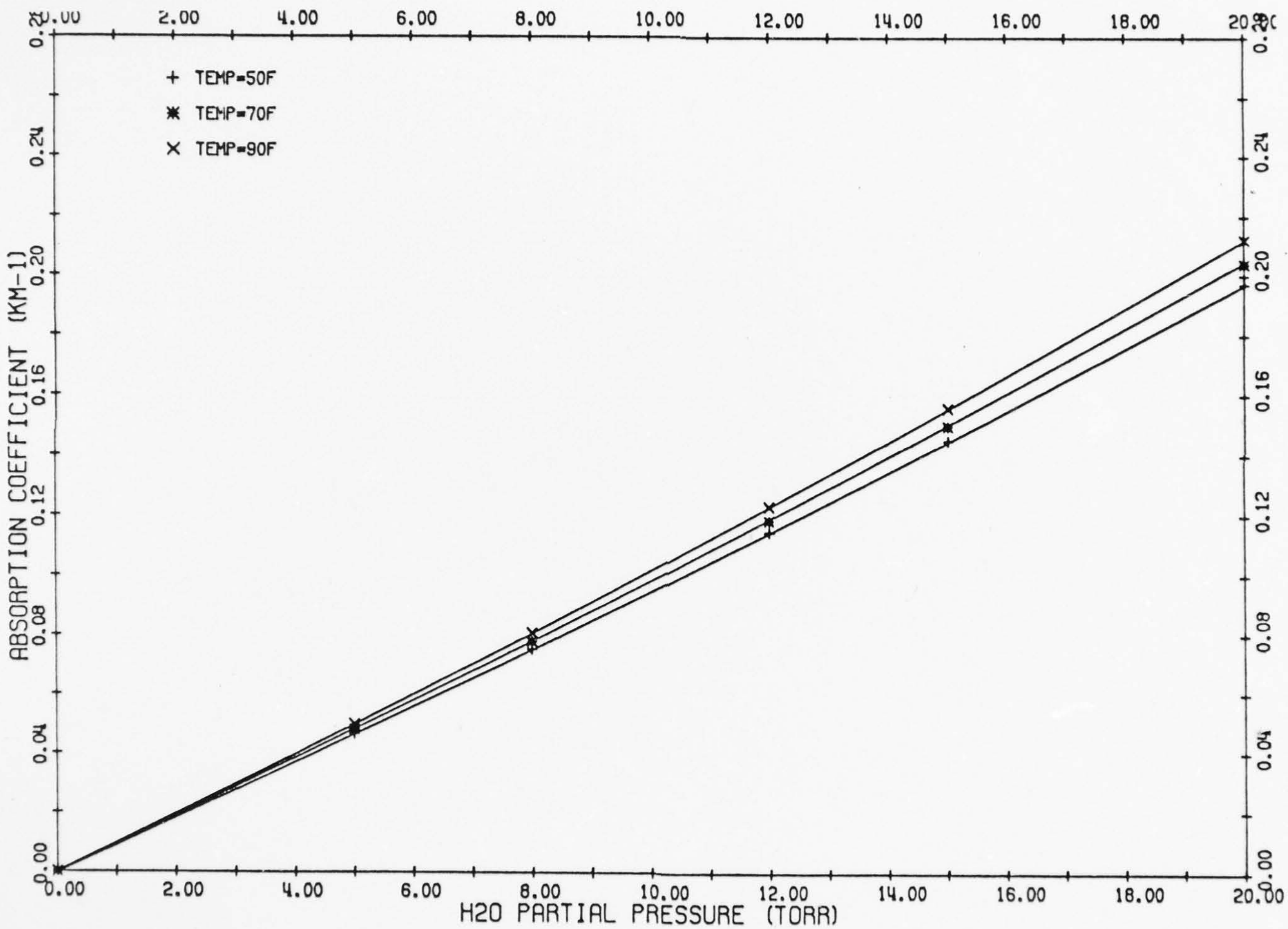


Figure 20. ABSORPTION COEFICIENTS FOR THE P1(8) DF LINE AT 2717.543 WAVENUMBERS

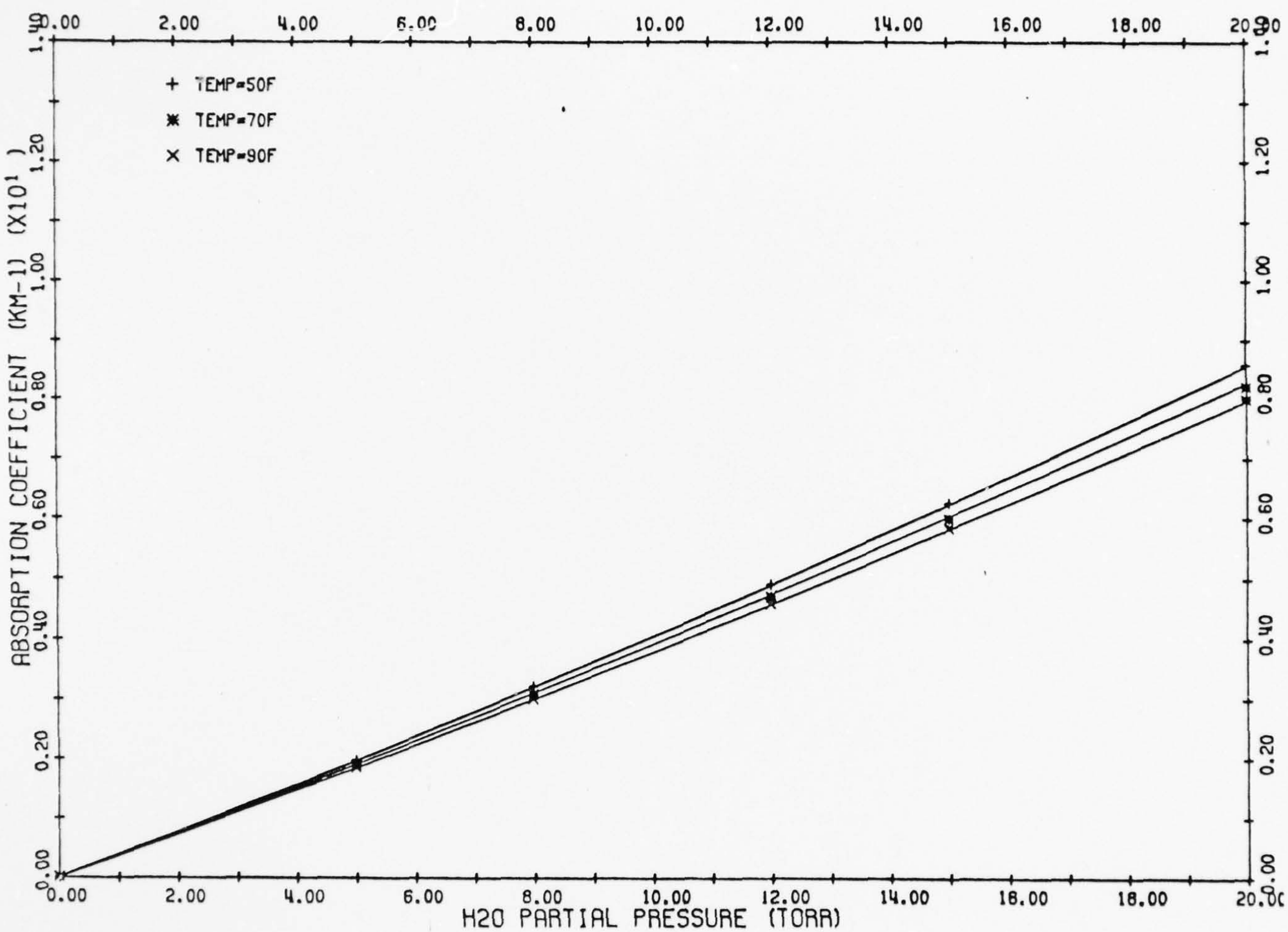


Figure 21. ABSORPTION COEFICIENTS FOR THE P2(4) OF LINE AT 2727.312 WAVENUMBERS

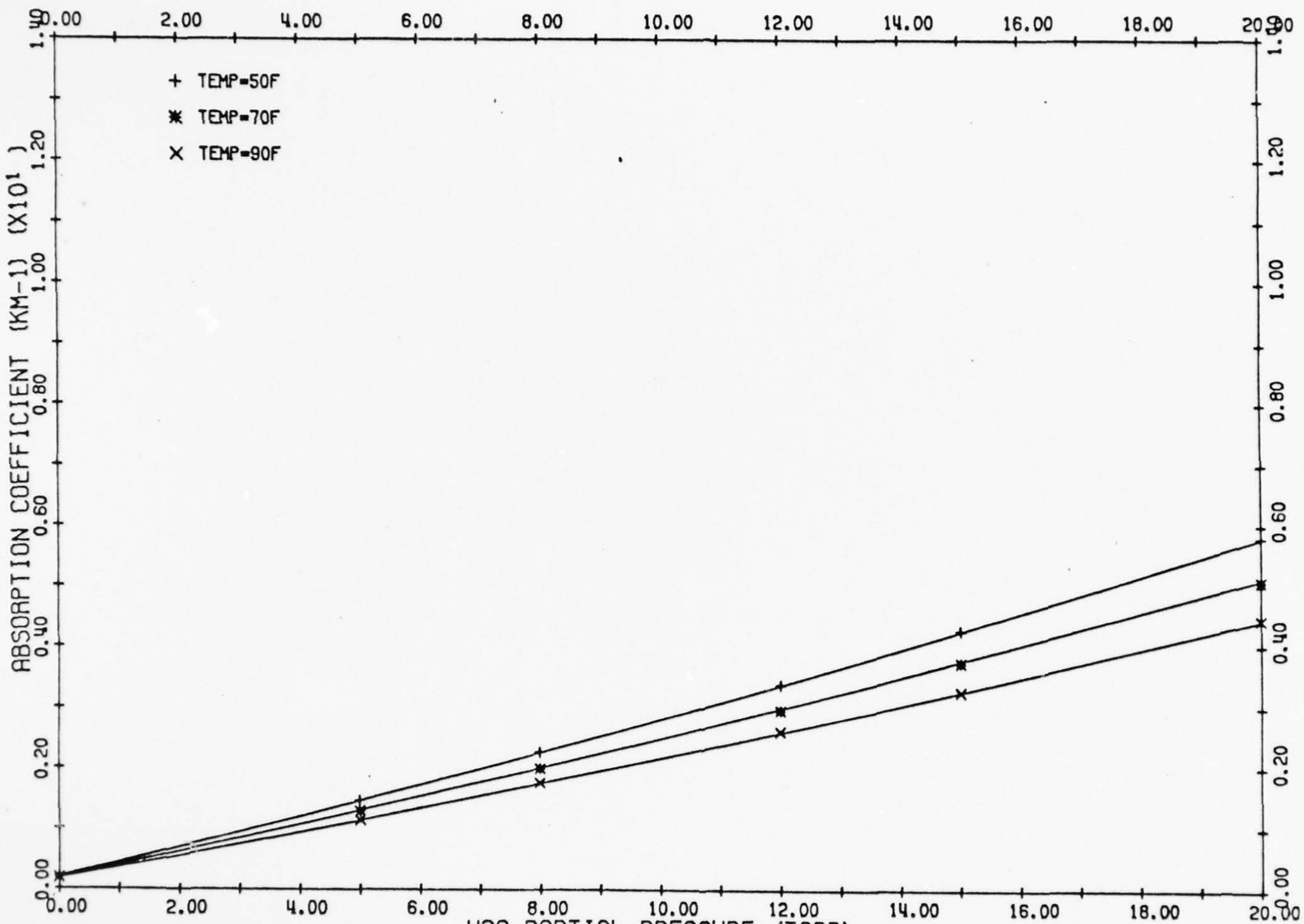


Figure 22. ABSORPTION COEFICIENTS FOR THE P1 (7) OF LINE AT 2742.988 WAVENUMBERS

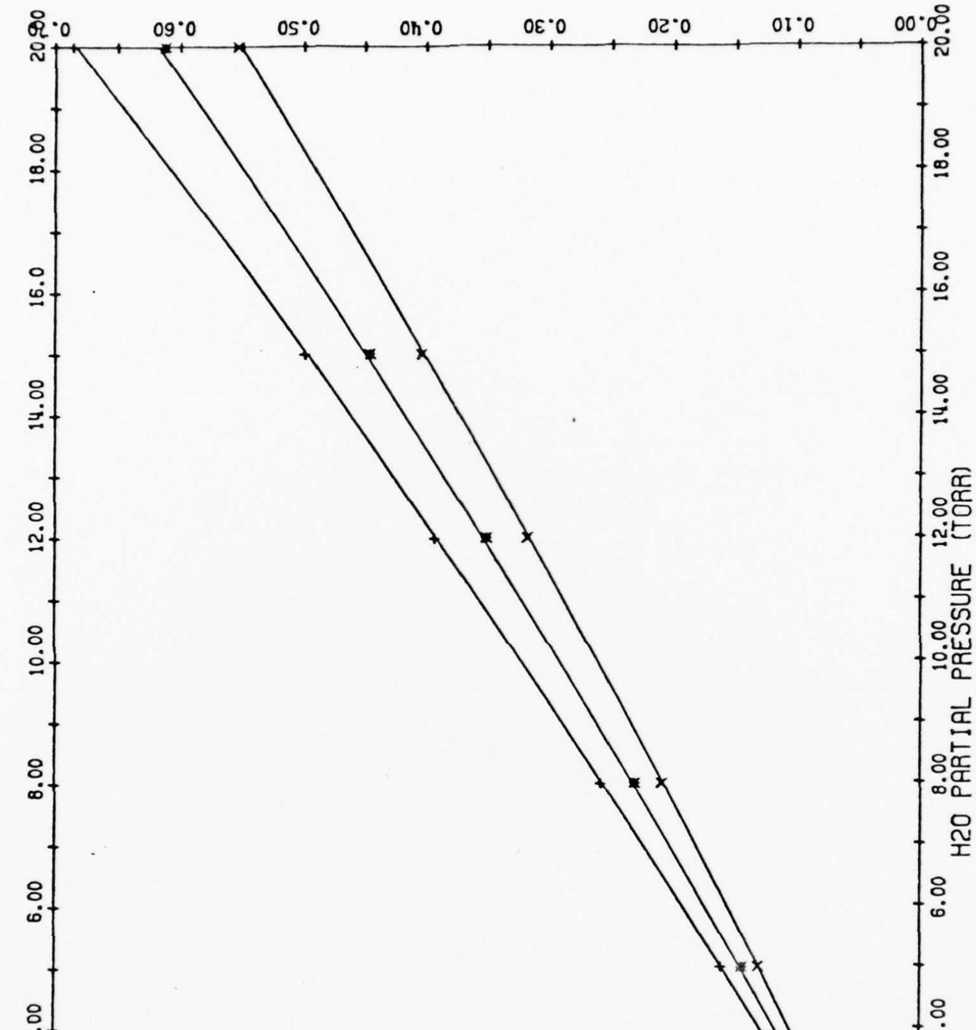


Figure 23. ABSORPTION COEFICIENTS FOR THE P2(3) OF LINE AT 2750.096 WAVENUMBERS

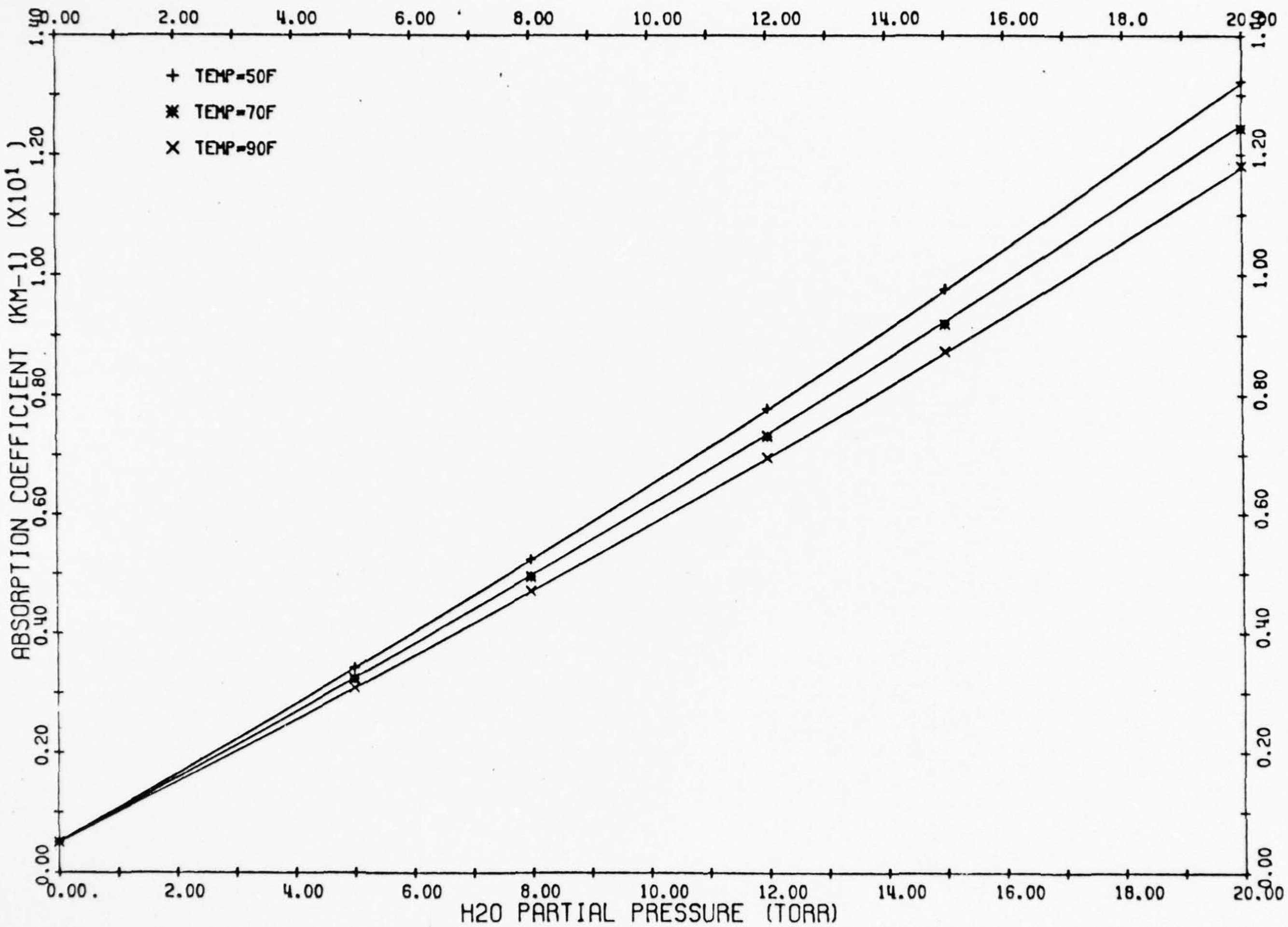


Figure 24. ABSORPTION COEFICIENTS FOR THE P1(6) OF LINE AT 2767.969 WAVENUMBERS

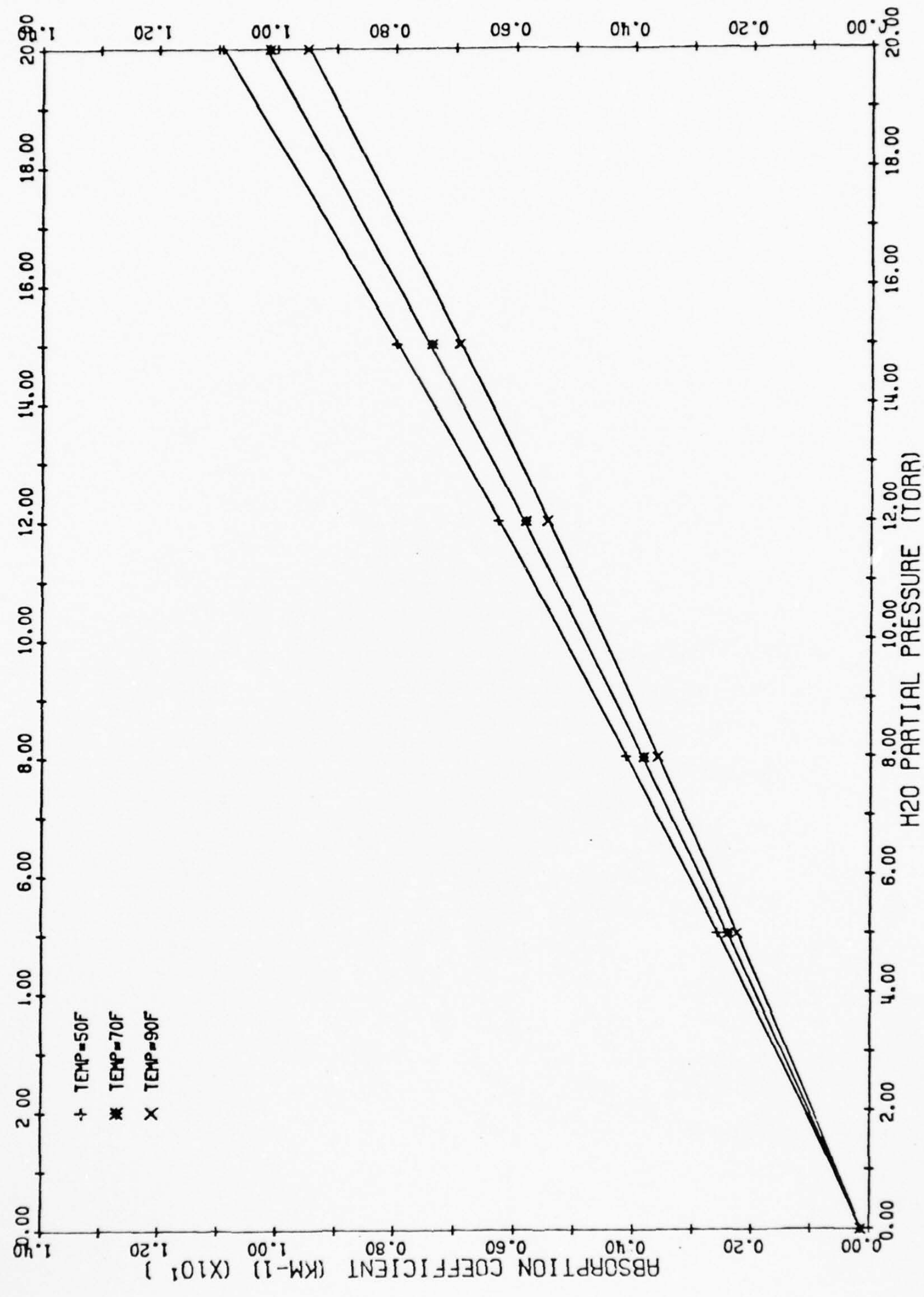


Figure 25. ABSORPTION COEFICIENTS FOR THE P1(5) OF LINE
AT 2792.434 WAVENUMBERS

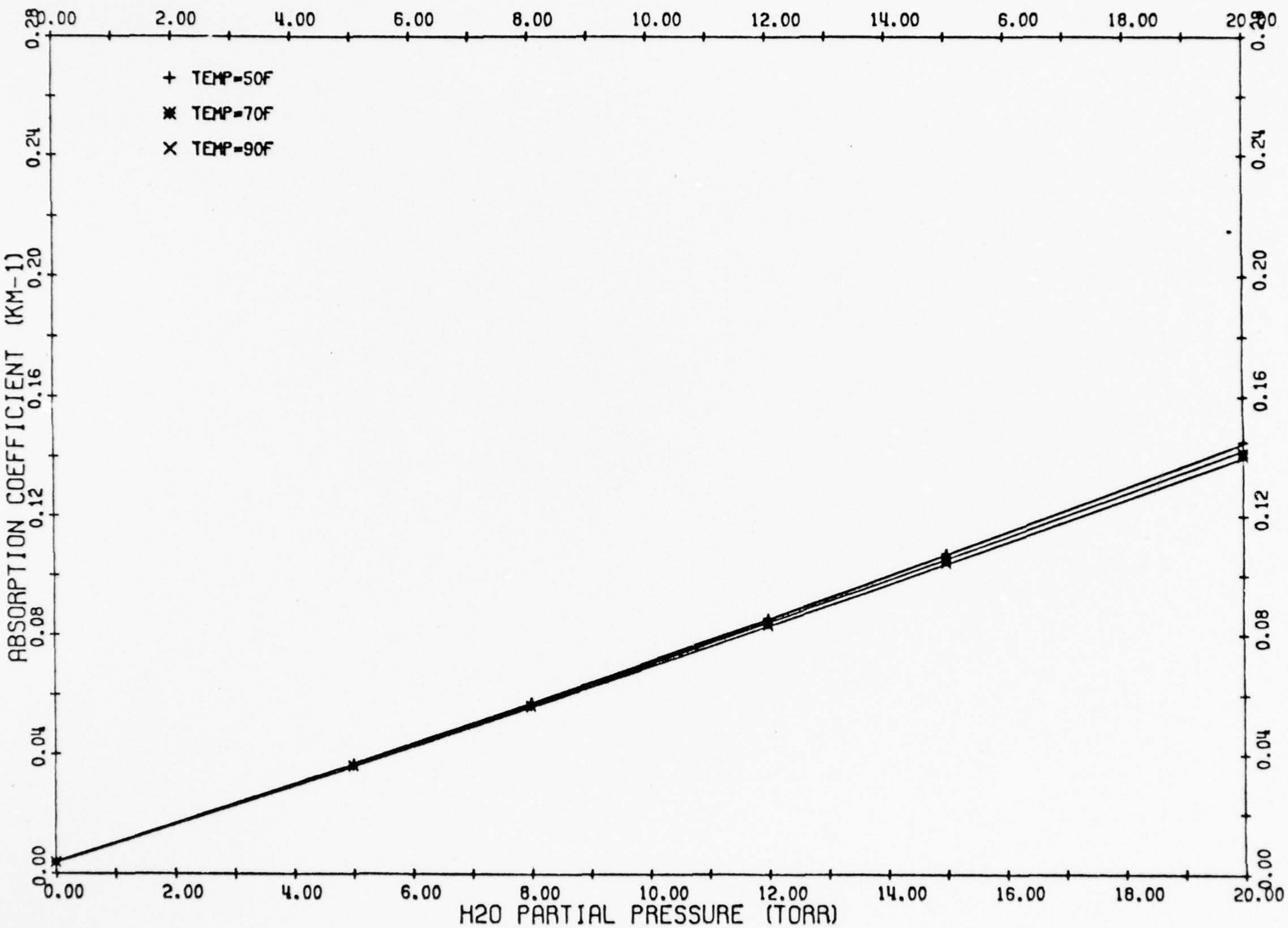


Figure 26. ABSORPTION COEFICIENTS FOR THE P1(4) OF LINE AT 2816.385 WAVENUMBERS

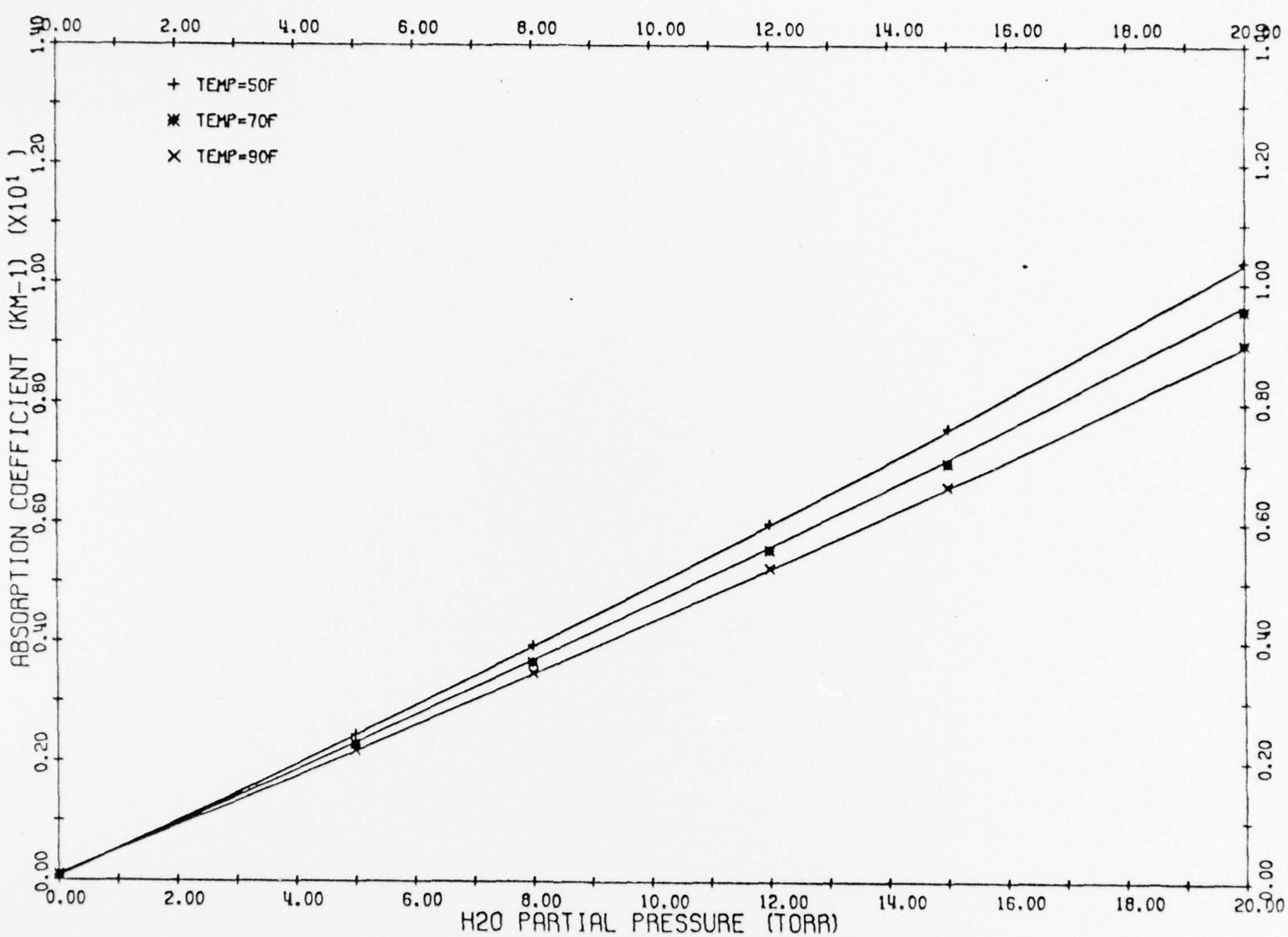


Figure 27. ABSORPTION COEFICIENTS FOR THE P1 (3) OF LINE AT 2839.795 WAVENUMBERS